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HABITAT PRESERVATION FOR MIDWEST STREAM FISHES:

PRINCIPLES AND GUIDELINES

by

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The degradation of running water resources is at least partly due to a lack of understanding of the physical and biological dynamics of stream and river ecosystems and to the lack of a comprehensive, integrated approach to watershed management. The report outlines such an approach, reviews physical and biological dynamics and presents a set of habitat preservation guidelines for maintaining ecological integrity, with emphasis on warm-water fish communities. Also presented are programs dealing with water resource problems in agricultural areas, with suggested institutional approaches for halting and reversing stream and river degradation.

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ABSTRACT

Natural and man-induced events (e.g., changes in land-use and channel modifications) exert major effects on biotic components of streams and rivers. Historically, man's efforts to reverse water resource degradation have emphasized physical and chemical attributes of water (water quality) while ignoring other factors that determine the quality of a water resource system. One of the most neglected components of water resource quality in stream ecosystems is physical habitat. Indeed, concern for in-stream/ near-stream physical habitat is as critical to restoring a fishery as is water quality. Among the primary man-induced stresses on fish communities (sedimentation, nutrient enrichment, navigation, impoundments and levees, toxic substances, consumption of water, altered hydrological regimes, introduction of exotics), most have major impacts on physical habitat conditions. Continuation of present policies yields little chance for compliance with society's mandate for preserving biotic integrity, an explicit objective of water resource legislation. Unless present activities related to aquatic systems are changed, the trend toward declining fish resources in most rivers will continue until only a few tolerant species with minimal aesthetic, recreational or food value remain.

The progressive degradation of running water resources is at least partly due to a lack of understanding of the physical and biological dynamics of stream and river ecosystems and to the lack of a comprehensive, integrated approach to watershed management. In this report we outline such an approach, review physical and biological dynamics and present a set of habitat preservation guidelines for maintaining ecological integrity, with emphasis on warmwater fish communities. We also analyze present programs dealing with water resource problems in agricultural areas and suggest institutional approaches for halting and reversing stream and river degradation in these regions.

This report was submitted in fulfillment of Grant No. 807677 by the University of Illinois under the sponsorship of the U. S. Environmental Protection Agency. This report covers a period from October 1980 to December 1981 and was completed as of 24 December 1981.

PREFACE

The surface waters of the United States absorbed effluents as well as other impacts of a developing society for several centuries before signs of degradation could no longer be ignored. A "dilution is the solution to pollution" approach to waste disposal prevailed and typically resulted in grossly polluted water and associated losses of aquatic resources (particularly fish). By the mid-twentieth century, early legislative efforts were initiated to halt and perhaps reverse this ominous trend.

A proliferation of programs to improve water quality ensued with decisions regarding management of running water resources being made by engineers and dealing with effluent control. The primary approach was to restore the chemical quality of water; it was presumed that improvements in biological quality would follow close at hand. In many cases, streams were viewed as conduits for the transport of water and water development schemes rarely included assessments of biological impacts. Many even denied the fundamental biological nature of aquatic systems and/or their complex interrelationships with terrestrial watersheds. As a result, habitat quality and thus biotic integrity continued to decline in many areas despite massive expenditures of funds. Ironically, man's "technological" solutions to water resource problems sometimes contributed to declines in biotic integrity (e.g., chlorine toxicity in the effluent of sewage treatment plants).

Individual water resource problems have traditionally been dealt with in a fragmented manner by groups or agencies with narrow water-use interests or concerns. Program planners typically lacked the disciplinary breadth to consider the full array of ecosystem functions and needs. As a result of these uncoordinated efforts and reliance on technological control measures, integral features of naturally functioning stream ecosystems are destroyed. Hence, desirable effects of specific water programs may precipitate negative secondary impacts. Minimal incremental improvement in biotic integrity often follows effluent control because physical habitat quality in streams and rivers is being degraded simultaneously by structural solutions to control agricultural nonpoint sources and channel alterations for navigation, flood control, and drainage.

In recent years, knowledge of the influences of biological dynamics have increased and a cadre of spokesmen have become more articulate at communicating the significance of those dynamics. The result is emergence of a more integrative perspective on goals for management of running water resources. In this report we focus upon the role of habitat structure as a determinant of biotic integrity.

Our goal is to provide a series of guidelines and recommendations that can be used to insure the preservation of physical habitat. The development of these guidelines and recommendations depends on a solid foundation in several disciplines. Most importantly, the preservation of suitable habitat requires identification of the major habitat components. This requires knowledge of both biological dynamics and hydrological conditions that produce specific physical habitat characteristics. Hence, we outline both the biological and hydrological background to our recommendations. We believe that biologists should no more ignore the hydrological underpinnings of the stream ecosystem than should engineers and hydrologists ignore the biological foundations.

The primary emphasis of our guidelines and recommendations is on physical habitat characteristics that are necessary to preserve or restore fish faunal integrity in warmwater streams and rivers of the Midwest. In formulating these guidelines we have conducted a comprehensive review of ecological literature dealing with relationships between physical parameters and stream fish communities. Although warmwater streams are our primary focus, we have included relevant supportive data from coldwater systems.

While effects of various types of habitat alterations provide part of the foundation for our guidelines, it is not our intent to develop a laundry list of ways that man impacts the integrity of physical habitat. In fact, intricacies of some water resource problems, particularly those relating to impoundments by high and low head dams, are not treated in detail. Rather, we deal with ecological consequences of impacts, emphasizing ways that negative aspects of those impacts can be minimized, as well as pointing out which impacts and practices are unacceptable. As a result, we believe that our guidelines and recommendations are adaptable to most warmwater stream environments.

Our report is organized into the following major components:

1. History and Background of the Problem

In this section we trace the historical roots of the crisis in habitat quality in warmwater streams. We examine fish faunas of several major midwestern basins and characterize specific factors that have produced changes in fish resources.

2. Guidelines and Recommendations for Protection of Physical Habitat in Warmwater Streams

In this section we outline guidelines to protect habitat characteristics of streams and rivers. In particular, we detail specific physical habitat attributes that must be maintained to preserve biotic integrity. We also discuss mitigation measures to insure the protection of important habitat characteristics when watershed modifications are initiated, as well as methods to restore previously altered streams. Finally, we describe comprehensive planning efforts, including suggestions regarding more effective institutional arrangements and policies that are necessary to protect stream ecosystems.

3. Development of Stream Habitat

This section outlines briefly the hydrological principles associated with the development of physical habitat in streams and rivers. An understanding of these hydrological processes is essential to comprehensive planning programs.

4. Biological Foundations for Habitat Protection

Since our primary concern is biotic integrity of streams and rivers, this section forms the central core of the background material. We discuss the most important relationships between physical habitat attributes and biotic integrity in flowing water systems, with special emphasis on fishes.

5. Annotated Bibliography

This annotated bibliography includes references that we found most useful in our search of the literature on the subject.

6. Appendix

Throughout the report we refer to fish species by common name only. In Appendix I we provide a list of the scientific names of those species. Appendix II lists the fishes of the Illinois River, their food habits, present population status, and population trends since the mid-19th century.

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To these persons, and to the many others who have contributed to our understanding of physical habitat of warmwater streams through their writings or discussion in person, we extend our thanks.

SECTION 1

INTRODUCTION

The characteristics of waterways are altered by natural and man-induced causes. Among man-induced occurrences, changes in land-use and channel modifications exert major effects on waterways and their biotic components. Historically, decisions to alter land-use or channel characteristics have been made on the basis of their local short-term impact rather than within the context of integrative, basin-level analyses. Regrettably, even local impacts have not been adequately assessed. In most cases, physical and chemical attributes of water are narrowly emphasized while other important determinants of water resource quality are neglected. As a result, running water resources have been, and continue to be, degraded.

One of the most neglected components of water resource quality in stream ecosystems is physical habitat. While the role of physical habitat as a determinant of biotic integrity is the primary focus of this report, it is important to view this factor in a wider framework (Fig. 1). The attributes of a running water ecosystem are determined by characteristics of the terrestrial environment of the watershed. The physical structure of stream channels and the flow regime that they support reflect the climate of the system as well as the topography, parent material, and land-use of the basin. These interact to produce the surface and groundwater characteristics and dynamics of the watershed. The riparian environment plays a major role in mitigating these influences at the land-water interface. Within the stream itself, five major sets of variables interact to affect biotic integrity (Fig. 2): water quality, flow regime, physical habitat, energy source, and biotic interactions.

Historically, of the five factors that affect biotic integrity, only water quality, and to a lesser extent, flow regime, have been of concern to water quality managers. We hope this report will reverse that trend by drawing attention to and outlining the importance of physical habitat. Treatment of water quality degradation without addressing physical habitat degradation will not result in attainment of legislative mandates on water resources.

Specifically, our objectives are to outline: 1. The importance of physical characteristics as determinants of fish community attributes in stream ecosystems; 2. how changes in physical characteristics affect fish faunas; and 3. guidlines and recommendations to halt and reverse the degradation of physical habitat. We hope this report will be of use to a variety of water resource planners and managers and that it will result in a more integrative approach to the management of water resource systems.

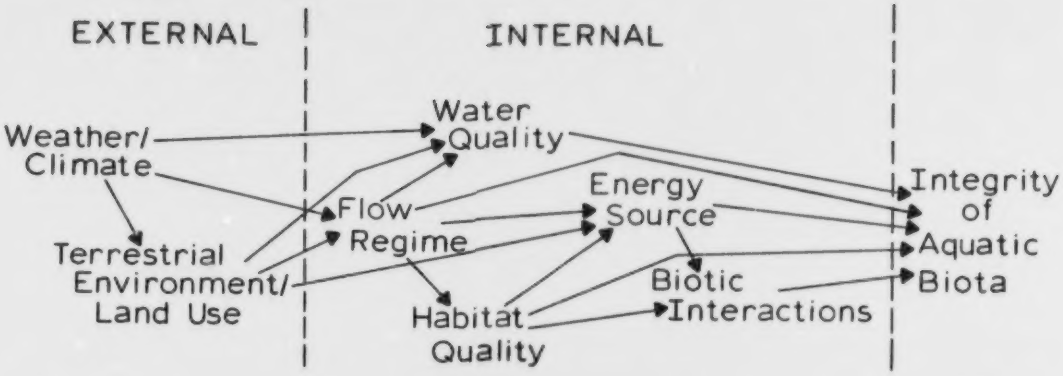
EXTERNAL
INTERNAL
Weather/ Climate
Terrestrial Environment/ Land Use
Water Quality
Flow Regime
Energy Source
Habitat Quality
Biotic Interactions
Integrity of Aquatic Biota

Figure 1. Conceptual model showing the primary variables (and their interactions) external and internal to the stream that govern the integrity of an aquatic biota (From Karr 1981a)

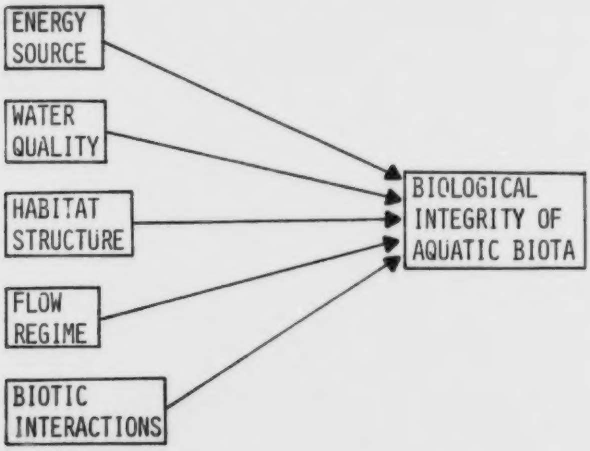
ENERGY SOURCE
WATER QUALITY
HABITAT STRUCTURE
FLOW REGIME
BIOTIC INTERACTIONS
BIOLOGICAL INTEGRITY OF AQUATIC BIOTA

Figure 2. Primary variables that affect the structural and functional integrity of an aquatic biota (Modified from Karr and Dudley 1981)

WATER RESOURCE QUALITY

The passage of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) stimulated many efforts to improve water quality through establishment and enforcement of criteria and standards for specific contaminants. The use of these criteria has been attacked on numerous grounds (Thurston et al. 1979). For example, they have not taken into account naturally occurring geographic variation of contaminants (e.g.,copper, zinc) or considered the synergistic and antagonistic effects of numerous contaminants; nor have they considered sublethal effects (e.g., reproduction, growth, behavior) of most contaminants. In addition, monitoring water quality parameters, such as nutrients, pesticides, dissolved oxygen, temperature, and heavy metals often misses short-term events and long-term patterns (e.g., shifting age structure of fish populations) that may be critical to assessment of biotic impacts. In addition, procedures for establishment of criteria have often involved inadequate or inappropriate controls or experimental conditions. For these and other reasons, the primary dependence on a chemical-contaminants approach is of limited value in attaining biotic integrity in running water ecosystems (Gosz 1980).

An additional disadvantage of this narrowly defined water quality approach is that several key determinants of biotic integrity are not evaluated (Karr and Dudley 1981, Karr 1981a). Chemical monitoring misses many of the man-induced perturbations that impair use. For example, flow alterations and physical habitat degradation, are not detected in chemical sampling.

This narrow focus developed because of inadequacies of early water resource legislation (PL 92-500). Although congressional hearings leading to passage of the law clearly indicate the intent to focus on biotic integrity,as drafted, the law emphasizes physical-chemical parameters and water quality. With passage of the Clean Water Act of 1977 (PL 95-217) a more comprehensive definition of pollution came into existence; pollution was defined as "the manmade or man-induced alteration of the chemical, physical, biological, and radiological integrity of water." Despite this refinement, regulatory agencies have been slow to replace the classical approach (uniform standards focusing on contaminant levels) with a more sophisticated and environmentally sound approach.

More effective water resource management requires integrative planning and coordination at the basin level. The many agencies and individuals involved in activities that affect water resource quality must coordinate their efforts more effectively. This involves development of more meaningful and less oppressive regulations whenever possible. It also involves each element in society participating in a spirit of responsibility and cooperation to protect the values of land-water ecosystems. The specific values to be protected vary with site and local needs. Nationally, we cannot afford continuing degradation of specific values (e.g., biotic integrity). The holistic perspective of ecosystems (and the values derived from them) as integrated systems of land-water-biota-human must be adopted by society at large.

MAN'S INFLUENCE ON STREAM HABITAT

Human population increases combined with technological impacts during the last 100 years have been instrumental in degradation of water resources. In midwestern North America, agriculture, urbanization, industrial development, navigation, hydroelectric development, and recreation have all had significant impacts on the physical attributes of lotic environments. Impacts of modifications such as dredging and dam construction on stream habitats are obvious, while others are more indirect. Urbanization, for example, alters watershed hydrology which affects stream habitat conditions by disrupting flow dynamics and channel equilibrium.

The complex interactions that have resulted in water resource degradation and attendant changes in fish faunas are illustrated by perturbations stemming from historical changes in agricultural ecology (Cox and Atkins 1979). The conversion to intensive agriculture has been particularly important in changing running water resources in the Midwest; indeed, it was probably the first major encroachment on inland waters (Cairns 1978).

Early settlers were limited, for the most part, to raising livestock and small plots of crops on naturally well-drained land that could be cleared of trees or prairie grasses (Larimore and Smith 1963). With the development of improved farming techniques and equipment (e.g., the steel plow), more land was cleared and fields expanded. Ditches were dug by individual farmers to drain marshy areas. Crop rotation, fallow land, and manure were used to replenish soil nutrients removed by crops and erosion.

In Illinois, the Farm Drainage Act of 1879 promoted the formation of drainage districts that allowed farmers to work together on drainage projects covering large areas (Larimore and Smith 1963). By 1920, 70% of the Illinois counties studied by Larimore and Smith had undergone drainage improvements. Bottomlands along rivers and streams were cleared of trees, ditches were dug, and underground tiles installed to lower the water table and accelerate groundwater flow to natural streams. In some places tiles resulted in burying what were originally surface water courses (Larimore and Smith 1963). Dredging and straightening of existing streams also increased the rate of drainage. Drainage impacts combined with environmental modifications associated with the initial tilling and draining of the prairie in the early 1800s had dramatic effects on stream environments. By the late 1800s many streams that were originally deep, narrow and of continuous clear, cool flow had become wide, shallow and widely fluctuating in discharge as a result of changing land-use (Menzel and Fierstine 1976). (see Section 3 for a discussion of the hydrological causes and consequences of these alterations.) In fact, changes in water flow regimes in streams combined with modifications of soil structure (resulting from clearing and cultivation) altered the dynamics of the entire ecosystem.

Overall, the development of legal (Farm Drainage Act of 1879), institutional (soil and water conservation districts), and technological (farm implements, pesticides, fertilizer) innovations speeded the shift to more intensive cultivation. Vigorous hybrids and improved varieties along with the use of herbicides and pesticides have, by increasing production, also led to reduced concern about natural soil fertility. "Soil-building" crop rotations have been abandoned in most areas and replaced by high-income crops that deplete nutrients in one year rather than over the course of a multiyear crop rotation (USDA 1981). Wheat, corn, and later, soybeans became the leading crops because they were marketable on a large scale.

With agriculture depending less, in the short-term, on natural fertility for sustained yields, and growing world markets in the 1970s, even marginal and poor lands are being cleared and cultivated. Farmers now more than ever put every available acre into production, often resulting in abandonment of conservation practices (Karr 1981a) and accelerated erosion rates.

In fact, erosion has once again become a serious problem. While the technology of agriculture has changed tremendously since the 1930s, the administration of Federal erosion-control programs continues to be carried out in much the same context as it was during the Depression, especially in terms of short-term, benefit/cost relations to the farmer, the landowner, and society at large (USDA 1981, Karr 1981a). In 1979, Rupert Cutler, then assistant to the Secretary of Agriculture, made the observation that "after 40 years of conservation efforts, soil erosion is now worse than during the Dust Bowl days" (Risser 1981). Rain and melting snow continue to wash tons of soil from fields. Much of that soil ends up in streams, rivers, and lakes, impeding the flow of water and destroying essential habitat for fish and other wildlife. In addition to sediment, livestock waste and chemical pollutants (nutrients, herbicides, and pesticides) carried by the soil also find their way into water systems.

With sediments from erosion clogging stream channels, dredging and rechannelization efforts have increased. Perpetual channelization of large rivers is also necessary to keep channels open for navigation. Part of the demand for navigable rivers lies in the need for barges to move grain and other products cheaply to ports. Thus, agriculture-related impacts, including drainage, erosion and sedimentation, nutrient enrichment, pesticide runoff, and altered hydrology, have clearly had a profound effect on water resources in streams and rivers.

Along the continuum from headwater streams to large rivers relative impacts of various perturbations change. Modifications due to agriculture seem to have their greatest direct effect on headwater streams. In addition to being subject to extensive channelization and removal of near-stream vegetation, headwater areas are the primary sites of sediment inputs from the land surface (Karr and Schlosser 1978).

Since these areas are important spawning and nursery grounds for commercial and sport species that spend their adult life in lakes or large rivers (Karr and Gorman 1975), modifications of headwater streams have wide-ranging as well as local impacts. (Also see p. 52).

In addition to channelization, hydroelectric, flood control, and recreational activities have direct and indirect effects on the hydrology and physical structure of large river environments. The most significant recent changes to the natural resources of the upper Mississippi River appear to be associated with navigation (Vanderford 1980). As early as 1824, the Federal Government authorized removal of snags, shoals, and sandbars, excavation of rock in several rapids, and closing off of meander sloughs and backwaters in an effort to confine flow to the main channel. By 1878, a 4.5 ft. (1.5 m) deep channel was authorized and was increased to 6 ft (2 m) in 1907 and 9 ft (3 m) in 1930. The last of the 9 ft (3 m) channels was completed in 1963 with the opening of the Upper St. Anthony Falls Lock.

Before the 9 ft (3 m) channel, the river bottoms were primarily wooded islands with numerous deep wetlands, lakes, and ponds scattered through wooded areas. The creation of a series of locks and dams and associated impoundments abruptly changed the river bottoms. Instead of a complex mosaic of habitats with widely fluctuating water levels, a series of navigation pools with relatively stable water levels was created. Navigation pools generally have three distinct zones: (1) an upstream zone much as it was before impoundment but with more stable water levels, (2) mid-impoundment area with flooded islands, oxbows, and other habitats, often with extensive marsh development, and (3) downstream areas with deep open water that precludes marsh development.

These changes resulted in the replacement of a natural river system that fostered fast-water fishery resources with an artificial pool system favoring a lake-type fishery. The slowed current affected spawning and nursery areas both directly and indirectly (e.g., through silt deposition). In addition, sedimentation destroyed many backwater areas. Overall, the navigation program on large rivers has affected fishery resources by modifying habitats as well as preventing migration among areas in the river system. Many species, such as skipjack herring, paddlefish, American eel, Alabama shad, shovelnose sturgeon, blue sucker, blue catfish, and lake sturgeon have been especially affected by these modifications and now occur in relatively low numbers (Carlander 1954).

The combined impacts of agriculture, urbanization, and navigation have resulted in massive degradation of physical habitat as well as water quality. Treatment of water quality degradation without addressing physical habitat degradation will not result in attainment of the legislative mandates on water resources. As is summarized in Table 1, alteration of physical habitat in streams creates a cascade of changes in numerous factors that reduce biotic integrity. We discuss many of these impacts and methods for reducing their negative effects throughout this report.

TABLE 1. ECOLOGICAL EFFECTS OF ALTERATIONS OF HEADWATER STREAMS (EXCLUDING CREATION OF SMALL IMPOUNDMENTS)

Water Quality Effects
- Increased suspended solids
- Increased turbidity
- Altered diurnal "DO" cycle
- Increased nutrients (especially soluble)
- Expanded temperature extremes

Flow Regime Effects
- Increased flow velocity
- Alteration in flow extremes
  (Both magnitude and frequency)
- Reduced diversity of flow conditions
  (No protected sites)

Habitat Quality Effects
- Decreased sinuosity
- Reduced habitat area due to shortened channel
- Decreased stability of substrate and banks due to erosion and sedimentation
- Uniform water depth
- Reduced habitat heterogeneity
- Decreased in- and near-stream cover

Energy Dynamics Effects
- Decreased coarse particulate organic matter input
- Increased algal production
- Shifts in invertebrate guilds
  (e.g. ↑ scraper, ↓ shredders)
- Shifts in fish guilds

Biotic Effects
- Altered production (1^{o} & 2^{o}) dynamics
- Altered decomposition dynamics
- Disruption of seasonal rhythms
- Shifts in species composition
- Shifts in relative abundances
- Increased frequency of hybrids

Downstream Effects
- Flooding and low-flow extremes
- Sedimentation
- Shifts in nutrient and organic inputs
- Shifts in biotic communities
  (e.g., fish communities are altered because of:
  a. local water, habitat, food availability
  b. modifications of headwater spawning and nursery areas
  c. modified competition and predation dynamics

CHANGES IN THE MIDWEST FISH FAUNA

Changes in watershed hydrology and channel structure have had a profound effect on fishes of Midwestern streams. Following Karr and Dudley (1978) we determined the current status and population trends (since about 1850) for each species in the Illinois River system and classed them according to food habits and typical stream size (Table 2). Like Karr and Dudley (1978) working on the Maumee River system in Ohio and Indiana, we assume that population trends since 1850 primarily reflect influences of man. A species was classed as decreasing if either or both of the following conditions were true: (1) The geographic extent of the species in the watershed has declined significantly, or (2) the average abundance of the species in suitable habitat is lower now than in the past. The extreme in this case is extirpation (extinction). At the other end of the spectrum are introductions of exotics and species that have increased in abundance.

The quality of information upon which the present status and population trends are based is marginal at best. Consequently, we use only a few general categories in our classification. Some subjectivity exists in this type of analysis due to the qualitative nature of the data base and because precisely equivalent information from both river systems is not available. However, in both river systems a significant amount of information is available to document major trends. We feel that classification errors are minimal and not likely to affect significantly the general conclusions.

Detailed knowledge of fish habitat requirements is not yet available. Thus, the impacts of man's activities on stream habitats can not yet be precisely related to changes in fish communities. However, study of food habits are relatively advanced, so changes in the food base can be used as a reasonable first approximation for habitat quality. The value of interpreting changing abundances of individual species by trophic status lies in the interpretation of changes which result from modifications in the entire watershed. The diverse functional roles of fishes makes them ideal organisms for study of biotic integrity in aquatic ecosystems (Karr 1981b).

According to the stream continuum hypothesis (Cummins 1974, 1975, Vannote et al. 1980), headwater streams in eastern North America are primarily heterotrophic and have coarse particulate organic matter from terrestrial environments as their major energy source (Table 3). Primary production in the stream is generally low. Medium-sized rivers are autotrophic with considerable primary production and fine particulate organic matter as energy sources. Large rivers tend to be more heterotrophic with the major energy source coming from upstream areas as exported fine particulates. Under this hypothesis, the changing energy base affects the stream fauna. Invertivore fishes should dominate in headwaters, invertivores and piscivores should dominate in medium-sized streams, and planktivores should dominate in larger rivers.

TABLE 2. CLASSIFICATION SYSTEM USED IN ASSESSMENT OF THE ILLINOIS RIVER FISH FAUNA

Distribution - Stream Size Category

1. Headwaters - Stream orders 1-3; generally less than 8 to 10 m wide; average discharge generally less than 5 cms.
2. Mid-River - Stream orders 4-6; about 10 to 35 m wide; average discharge 5 to 150 cms.
3. Large River - Stream orders 7 and above; greater than 35 m wide; average discharge generally exceeds 150 cms.

Food Habits

1. Invertivore - food predominantly (>75%) invertebrates.
2. Invertivore/Piscivore - food a mixture of invertebrates and fish; relative proportions often a function of age.
3. Planktivore - food dominated by microorganisms extracted from the water column.
4. Omnivore - two or more major (<25% each) food types consumed.
5. Herbivore - feed mostly by scraping algae and diatoms from rocks, and other stream substrates.
6. Piscivore - feed on other fish.

Food habits information obtained from Carlander 1969, 1977; Smith 1978, Karr and Dudley 1978.

Current Relative Abundance[a]

A - Abundant. A numerically dominant species.
VD - Very common. A species that is usually captured in large numbers.
C - Common. A species found in moderate numbers.
U - Uncommon. A species occurring rather regularly in collections, but usually in small numbers.
R - Rare. A species recorded only once or very infrequently, and invariably in small numbers.
E - Endangered. Species on the State of Illinois endangered species list.
X - Extirpated in watershed.

Population Trend[a]

S - Stable. No major change in abundance.
I - Increasing. Marked increase in abundance.
D - Decreasing. Marked decrease in abundance.
N - Introduced. Non-native species now present through release or invasion and native species whose presence is due primarily to stocking and escape from ponds.
E - Lost. Species whose numbers have been so drastically reduced they are considered extirpated or extremely rare.

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[a] Current abundance and population trends are based upon work of Trautman and his colleagues (cited in Karr and Dudley 1978) for the Maumee, and work by staff associated with the Illinois Natural History Survey (Mills et al. 1966, Sparks 1977, Smith 1979, Sanderson 1980) for the Illinois River.

TABLE 3. GENERAL CHARACTERISTICS OF PREDOMINANTLY FORESTED RUNNING WATER ECOSYSTEMS OF EASTERN NORTH AMERICA (MODIFIED FROM CUMMINS 1975)

Stream size	Primary energy source	Production (trophic) state*	Light and temperature regimes	Trophic status of dominant	
				Insects	Fish
Small headwater streams	Coarse particulate organic matter (CPOM) from the terrestrial environment Little primary production	Heterotrophic P/R<1	Heavily shaded Stable temperatures	Shredders Collectors	Invertivores
Medium-sized streams	Fine particulate organic matter (FPOM), mostly Considerable primary production	Autotrophic P/R>1	Little shading Daily temperature variation high	Collectors Scrapers (grazers)	Invertivores Piscivores
Large rivers	FPOM from upstream	Heterotrophic P/R<1	Little shading Stable temperatures	Collectors	Planktivores Omnivores

*A stream is autotrophic if instream photosynthesis exceeds the respiratory requirement of organisms living in the area (that is, P/R>1). It is heterotrophic if importation of organic material from upstream areas or the land surface is necessary (that is, P/R<1).

Shifts in land-use and other activities of man alter these patterns (Table 4; see also Karr and Dudley 1978, 1981, Schlosser 1981a,b). Modified headwaters, for example, support more opportunistic invertivores. In addition, migrants to headwaters from downstream areas shift from a dominance by invertivores and piscivores to omnivores and herbivores.

Before embarking on analysis of the Illinois River system, we summarize the major results of the Maumee River study (Karr and Dudley 1978). Seventeen species have been extirpated from the Maumee during the past century and an additional 26 species have declined in abundance. In contrast, 11 species were introduced, and 10 have increased. Populations of an additional 34 species have remained relatively stable. Overall, 43% have declined while half as many (22%) have been introduced or increased in abundance. The remainder (35%) have stable populations.

Trophic structure of the Maumee River fish fauna shifted most in medium-sized rivers. Nine invertivore/piscivore species (including gamefish such as northern pike, walleye, and smallmouth bass) declined in abundance since 1850. Deteriorating water quality as well as destruction of headwater spawning habitat were cited as reasons for the declines. Changing conditions in headwater streams impacted fish both locally (in headwaters) and in substantial portions of downstream areas. Karr and Dudley (1978) suggested that functional alterations in streams were particularly disruptive to the fish community because reduced populations of top predators removed natural checks on forage fish.

Among the species extirpated during the past century, four were headwater invertivores requiring clear water and in most cases clean gravel for successful breeding. Two additional headwater species, the central mudminnow (an omnivore) and pirate perch (an invertivore) require well-vegetated, slow moving streams and marshy areas that probably disappeared as a result of widespread drainage programs (Smith 1979). Thus, headwater "specialists" seem to be especially susceptible to extirpation.

Among the 10 native species with increasing populations in the Maumee, three are opportunistic at lower trophic levels - gizzard shad, quillback and bigmouth buffalo. The increase in these species, in conjunction with the introduction of carp and goldfish, shifted the system away from dominance by insectivore-piscivores toward dominance by omnivores. Small impoundments may have been instrumental in the success of these introductions as well as the increase in native omnivore populations. The consequent shift in midriver species composition to dominance by planktivores and omnivores has resulted in different types of fish moving into headwaters to feed and/or reproduce.

TABLE 4. GENERAL CHARACTERISTICS OF NATURAL FORESTED (CUMMINS 1974) AND MODIFIED (KARR AND DUDLEY 1981) HEADWATER STREAMS IN EASTERN NORTH AMERICA.

Parameter of interest	Natural	Modified
Water quality		
Light and temperature	Heavily shaded Stable temperatures	Open to sunlight Very high summer temperature
Dissolved oxygen	Relatively stable	Highly variable
Suspended solids concentration	Low to very low	Highly variable
Dissolved ions	Generally low	High, especially for P and N
Flow regime		
Flood events	Dampened hydrograph	Hydrograph peaks sharp and severe
Low flows	Moderately severe only in dry years	Moderately severe each year in late summer and early fall; extremely severe in dry years
Habitat structure		
Pools, riffles, and raceways	Substrate sorting and water depth distribution complex both along and across stream channel	Reduced and/or destroyed by channel maintenance activities
Sedimentation	Minor	Major problem with large sediment inputs from land and unstable banks;
Energetics		
Particulate organic matter size and source	Predominantly coarse particulate organic matter from forested terrestrial environment	Less coarse and more fine particulateorganic matter from agricultural (including livestock) and domestic sewage
Production (trophic) state	Little primary production Heterotrophic;P/R<1	Algal blooms common Autotrophic; P/R>1
Trophic status of dominant		
Insects	Shredders, collectors	Collectors, scrapers
Fishes	Invertivores	Opportunistic invertivores, omnivores
Migrant fishes	Top predators Many invertivores	Mostly filter feeders and/or omnivores

In our analysis of the Illinois River, we sought to answer the following questions: Do the trends observed in the Illinois River parallel those of the Maumee? If not, how do they differ? What ecological or other factors are responsible for the differences?

Before answering those questions, we summarize the general characteristics of the two watersheds (Table 5). The larger size of the Illinois River watershed accounts for its higher flow and richer fish fauna. The distribution of fishes among the three major size-classes of streams shows that 70% of the increased species richness in the Illinois is due to additional large river species, and is probably a result of the greater length of river in that size-class. Headwater and midriver regions each account for only 15% of the increase in species richness.

TABLE 5. SUMMARY OF CHARACTERISTICS OF MAUMEE AND ILLINOIS RIVER SYSTEMS.

		Flow	Number of Fish Species			
River	(Area km^2)	m^3/sec	Total	HW	MR	LR
Maumee	17,000	134.0	96	36	47	13
Illinois	72,300	632.8	131	41	52	38

The number (and percent) of species extirpated in the Illinois River is below that of the Maumee River. Two possible explanations are likely: (1) In the Maumee a species was classed as extirpated if lost from the watershed or "extremely rare". In analysis of the Illinois River only missing species are classed as extirpated. This leads to an overestimate of extirpation in the Maumee relative to the Illinois. (2) In the Illinois River many species persist only in small isolated areas of the watershed (see distributional maps in Smith 1979). Perhaps the larger size of the Illinois watershed and its more complex topography provides isolated refuge areas that have been minimally disturbed by man.

Species with decreasing populations (Fig. 3) are more common in all regions of the Illinois than the Maumee (61% vs. 27% for all river regions combined, respectively). The Maumee River had few species with decreasing populations in large river areas when compared to the Illinois, mainly because the Maumee fauna contains relatively few large river species. However, the Maumee River biota also has not been subject to any habitat modifications comparable to the impact of the Chicago sewage diversion (Mills et al. 1966, Sparks 1977) or activities associated with maintenance of the Illinois River as a navigable waterway. As in the Maumee, declines by headwater species are likely

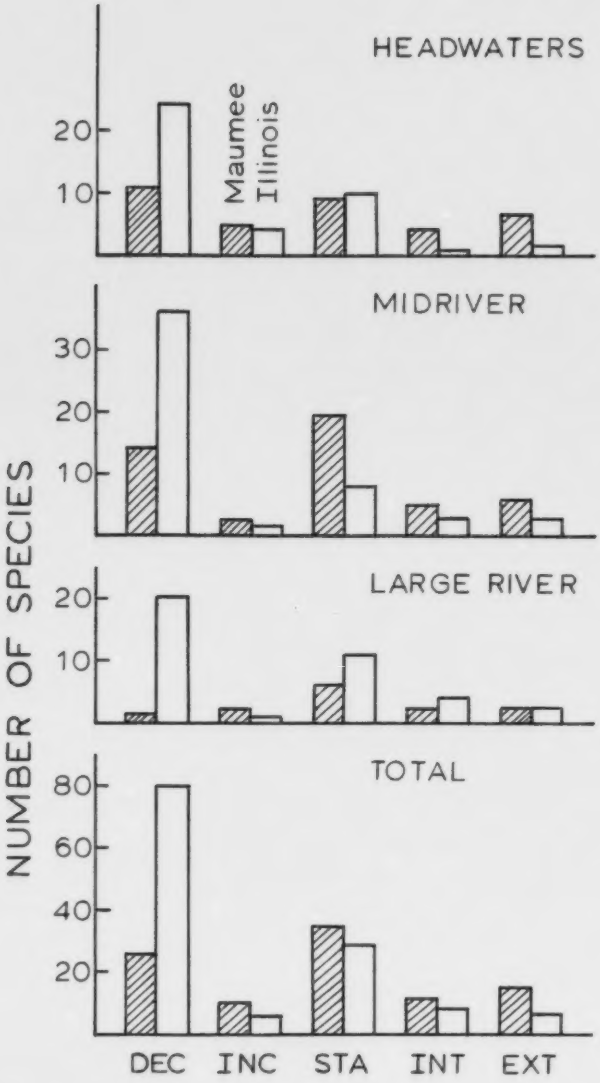

Figure 3. Population trends for the fishes of the Maumee and Illinois Rivers since about 1850. (DEC-Decreasing; INC-Increasing; STA-Stable; INT-Introduced; EXT-Extirpated)

due to changes in land-use (primarily agriculture) and channel alteration impacts, such as those associated with drainage.

The trophic status of the declining species also provides some insight into the ecological reasons associated with changing populations. Declining headwater species represent a broad spectrum of trophic groups in both watersheds (Fig. 4). However, in midriver and large river areas only invertivores and/or invertivore-piscivores have declined in the Maumee. In contrast, declining species in the Illinois River include species in all major trophic groups (Fig. 4).

Poor condition of fish in the main channel Illinois River indicates that there are additional causes for the declines. The weight/length ratio of Illinois fish seems to have declined suggesting, along with other data (Sparks 1977, pers. commun.), that food supplies are limited. In addition, the high frequency of tumors, eroded fins, and other anomalies suggests that a toxic(s) problem also exists.

Fewer species in the Illinois River show increasing populations than in the Maumee. Indeed, even carp (normally considered tolerant) have declined in the Illinois to the point where a major commercial fishery has disappeared.

Thus, it is likely that several additional human influences in the Illinois River watershed account for its greater fish faunal changes relative to the Maumee. Agricultural impacts (siltation and drainage) have had major effects in both areas. However, the Lake Michigan diversion and associated toxics as well as the maintenance of a navigation channel and degradation of floodplain lakes have magnified the disruption of the fish fauna of the Illinois River. Together these disruptions have exceeded the natural resiliency of the river ecosystem.

Although no similar comprehensive analyses are available from other major midwestern river systems, several smaller watersheds have been studied in some detail. We repeat the primary conclusions of those efforts to demonstrate that the Maumee and Illinois Rivers are not atypical.

Larimore and Smith (1963) examined 60 years of collection records on the fishes of Champaign County, Illinois. They showed extirpations of the following fish: speckled chub, bigeye chub, bullhead minnow, blacknose shiner, bigeye shiner, pugnose minnow, smallmouth buffalo, and bluntnose darter. In addition, extirpation of seven other species - bigmouth buffalo, black buffalo, pallid shiner, slender madtom, spotted sunfish, and slough darter - was almost certain. Seven other species in Champaign County declined, including black crappie, orangespotted sunfish, black bullhead, and grass pickerel (Larimore and Smith 1963). Overall, the disappearance of native fish from Illinois can be traced to the following factors: siltation, drainage, dessication during drought, species interactions, pollution, impoundments, and thermal changes (Smith 1971).

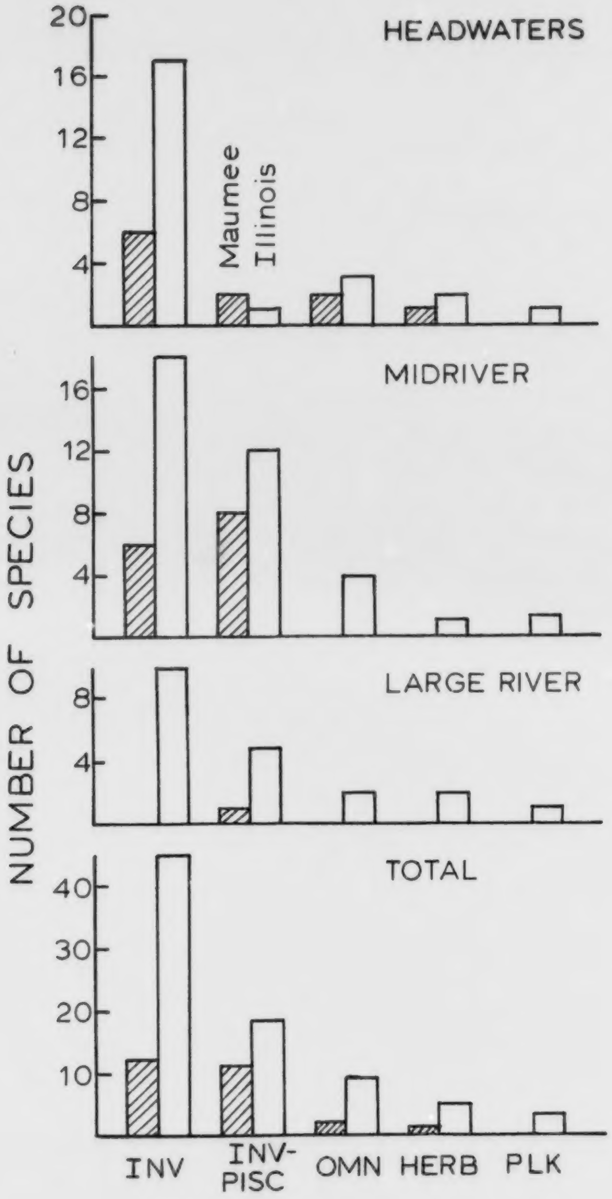

Figure 4. Number of decreasing and/or extirpated species by food habits groups for the Maumee and Illinois Rivers. (INV-Invertivore; INV-PISC--Invertivore-Piscivore; OMN-Omnivore; HERB-Herbivore; PLK-Planktivore).

In the upper Des Moines River basin in Iowa, eleven species have been extirpated, primarily as a consequence of conversion to intensive agriculture (Menzel and Fierstine 1976). Most of the extirpated species (e.g., silver lamprey, grass pickerel, blacknose shiner, brook silverside) require clear water, stable substrates, and permanent flow. Other changes in the fish fauna of the upper Des Moines River include a reduction in species richness and striking increase in carp abundance. At present, refuges in some headwater areas and especially in high gradient areas downstream of low gradient streams serve as sources of recolonists. If these areas are disturbed or migration routes are blocked, another round of shifts in the fish fauna can be expected (Menzel and Fierstine 1976).

As in Indiana, Illinois, and Iowa, the fish fauna of Kansas has been subjected to a series of changes catastrophic to the more intolerant species (Cross and Collins 1975). Six species of fish disappeared from Kansas streams since the advent of intensive land- and water-use. Two species were apparently lost in the Dust Bowl drought of the 1930's - the bigeye chub and the pugnose minnow. The pronounced loss of many species has continued with recent declines by hornyhead chub, Topeka shiner, common shiner, smallmouth bass and sauger. The cause of these declines by Kansas fishes is similar to that in other midwestern states (agriculture). However, impoundments and uncontrolled consumption of water in the face of lower annual rainfall are also important in the prairie regions of Kansas.

Thus, since 1850 overall impacts of man on fish communities of warmwater streams have been significant. The factors with greatest impact seem to be:

agriculture - changing land-use and resultant drainage, erosion sedimentation, and nutrient enrichment.

navigation - maintenance of navigation locks and channels in large rivers.

impoundments and levees

toxics - from urban, industrial, and agricultural sources.

consumption of water

introduction of exotics

Most of these (except toxics and exotics) have major impacts on physical habitat conditions although habitat has received relatively less attention than toxic impacts. Agriculture has clearly had the broadest impact. Urban and industrial development influences are typically more localized, but their impacts on those small areas are generally more intense. In addition, large urban and industrial areas may have more widespread effects, such as in the case of sewage diversion from the Chicago metropolitan area into the Illinois River.

It is difficult to develop an extensive set of general principles from these analyses, but several conclusions seem clear:

1. Several human activities have major impact on fish faunas (pp. 4-7).

2. These include both extirpations and numerous species with declining abundances (p. 13).

3. Other species have increased in abundance, especially species more tolerant of habitat degradation and with more generalized food habits (p. 15; Karr 1981b).

4. Trophic structure of communities is markedly altered (pp. 15-16).

5. As watershed size increases, the number of extinctions declines This is probably related to the relative availability and persistence of isolated refuges in larger watersheds (p. 13).

6. Because of extensive migration of fish among river reaches, the range and magnitude of local impacts on fish communities may be vastly extended (pp. 6 and 52).

7. In areas with combined agricultural, industrial and urban perturbations, the aquatic system is devastated and there is very little chance for recovery with continuation of those impacts (p. 17).

8. The degree of recovery possible depends on the degree of disruption. Unless present activities related to aquatic systems are changed, the trend toward declining fish resources in most rivers will continue until only a few tolerant species with minimal aesthetic, recreation, and food value remain (pp. 4-17).

EXISTING WATER RESOURCE PROGRAMS IN AGRICULTURAL REGIONS

Although stream habitat degradation results from a number of human activities, agriculture, either directly or indirectly, impacts the largest portion of midwestern streams. Several ongoing agricultural programs have been used to address water resource problems but have been largely ineffective in reversing trends toward degradation. In this section we outline what we feel are shortcomings of these programs in regard to water resource management and conservation (Karr 1981a).

SCS Conservation Farm Plans. This Soil Conservation Service program coupled with 3,000 locally organized soil and water conservation districts has been the central core of soil and water conservation programs for over four decades. Unfortunately, these efforts have been hindered by several major weaknesses including: (a) emphasis on land drainage and increased resources, (b) ineffective enforcement of legislation even in cases of abusive use of land and water resources, due to delegation of regulatory powers to local districts, (c) voluntary programs allowing landowners to accept or reject any or all portions of specific plans. Thus, components that have production-oriented values may be implemented along with those that have some cosmetic value while the more important conservation components can be ignored. It is even possible for a conservation practice with expensive government "cost-sharing" to be abandoned or removed a year after installation.

Agricultural Stabilization and Conservation Service. Agricultural Stabilization and Conservation Service (ASCS) plays the primary role in carrying out federal programs involving price-supports, commodity loans, target prices, set asides, conservation cost-sharing, and related farm programs. However, less than half of the money in the cost-sharing program--$190 million for fiscal year 1977--was used for measures primarily oriented toward conserving the nation's topsoil; most went for improving crop yields (GAO 1977).

Small Watershed (PL-566) Plans. Like in the SCS Conservation Program mentioned above, local sponsors have final authority over what each plan contains. Emphasis on short-term economic gain results in high cost-sharing (90+%) for drainage and flood control and much lower cost-sharing (50%) for fish, wildlife, and recreation benefits

Resources Conservation Act of 1977. The growth of soil and water conservation mandates for USDA and especially SCS created a decentralized conservation program with at least 41 individual legal activities (USDA 1980a). These, combined with a plethora of local districts and a variety of state programs, have operated without a general review. As a result, Congress passed the Resources Conservation Act (RCA) of 1977 to take a fresh look at these programs and their value to the future of soil, water, and other resources in the U.S. Although the overall thrust of first draft RCA documents perpetuated production oriented objectives without really coming to grips with present and future resource problems, a recent draft proposes more effective programs to halt and reverse soil and water degradation. Clearly, the drafters of RCA documents recognize that maintenance of the status quo will result in progressive decay of soil and water resources, including disasterous consequences for the biota of running waters. Vigilance will be required to insure that the excellent intent of the RCA process is not reoriented as happened following the initial crisis of the dustbowl era.

Food and Agriculture Acts. An additional weakness of ongoing approaches is the failure to implement programs that are enacted and well-conceived. The Food Act of 1970 required farmers to participate in a set-aside program to be eligible for crop loans, purchases, and payments. Similar provisions in the Food and Agriculture Act of 1977 called on farmers to devote set-aside acreage to approved conservation uses. However, uncertain market conditions limit set-aside programs to one year instead of long-term contracts. The 1973 Agriculture and Consumer Protection Act provided the Secretary of Agriculture with authority to write multiyear set-aside contracts with payments for vegetative cover. That authority was never used.

Rural Clean Water Program. This program like so many others (e.g., 208 plans; Karr and Dudley 1981) is dominated by the assumption that control of soil erosion will solve water quality problems and result in improved biotic integrity.

Summary of Program Weaknesses. In short, soil and water conservation programs have been less successful than their designers had hoped. The diversity of complicated, competitive, and even contradictory, programs is certainly one factor responsible for many failures. But the problem is deeper than that of too much legislation and too many programs. The deflection of programs from primary objectives (such as SCS and ASCS emphasis on production and drainage rather than soil and water conservation) illustrate a critical problem not envisioned in enabling legislation.

An admirable objective might be to bring each parcel of land into productivity at a level that is related to its potential in an effort to prevent abuse of land and water as well as wetland environments. We must give more explicit attention to maintaining and expanding productive capacity over the long run and doing so in a broader social context (USDA 1981). Tradeoffs must be found between operating at maximum production in the short run, with severe environmental degradation, and sustained, long-run production with environmental enhancement.

SECTION 2

PRINCIPLES, GUIDELINES AND RECOMMENDATIONS

I. PRESERVATION OF PHYSICAL HABITAT CHARACTERISTICS

A. General Principles and Guidelines

1. Physical characteristics of streams and rivers are ultimately determined by watershed characteristics and natural fluvial processes.

2. The water-sediment discharge regime is the proximate determinant of key interrelationships among physical characteristics of streams and rivers.

3. These complex interrelationships form the basis of habitat structure and stability which, in turn, are important determinants of ecological integrity in streams and rivers.

B. Major Habitat Divisions

1. Principles and Guidelines

   a. Natural fluvial processes lead to the development of distinct habitat types with characteristic physical and chemical attributes that vary with discharge.

   b. Excessive sediment loads obliterate the distinction between pools, riffles, and raceways and are largely responsible for the degradation of side- and extra-channel habitats.

   c. Fish species are associated to various degrees with these habitat types.

   d. Pools are particularly critical for maintaining populations of sport fishes and top predators, and provide important refuges for many other species during low flow periods.

   e. Riffles and raceways are indispensable to species that are adapted to faster flowing and shallower water conditions and also serve as nursery areas for many pool species. Riffles are also a primary site of aquatic invertebrate production (a major component of fish food chains).

   f. Side- and extra-channel habitats (i.e., sloughs, side streams, and backwater lakes and ponds) are invaluable feeding, spawning, rearing, and overwintering areas for riverine fishes.

g. The absence of one or more habitat types will almost assuredly result in the absence of some fish species and adversely affect populations of many others.

2. Recommendations

a. A fundamental requirement for maintaining fish community integrity in streams and rivers is the preservation of all natural habitat divisions that normally occur within the hydrologic and physiographic constraints in the watershed. This must include pools, riffles, and raceways, as well as side- and extra-channel habitats and their connections to main river channels.

b. To preserve the full complement of habitats, dynamic features of running water ecosystems must be maintained. Disruption of natural channel pattern (especially meandering) and water-sediment discharge regimes must be minimized except in special cases such as protection of dwellings, roads, and bridges.

C. Riparian Environments

1. Principles and Guidelines

a. Nearstream vegetation plays a particularly critical role in regulating water temperatures and channel morphology, stabilizing stream banks, trapping eroding sediment from the land surface, providing cover for fish. Nearstream vegetation also serves as a nutrient and energy source for instream invertebrate populations, and habitat for terrestrial invertebrates (an important fish food source).

2. Recommendations

a. The importance of riparian vegetation to ecological integrity in stream ecosystems must be reflected more clearly in water and land management policies, programs, and practices (Jahn 1978).

b. The essential functions of nearstream vegetation can be maintained with a vegetated buffer strip at least 25 m wide on each side of small, low to medium gradient streams (Brazier and Brown 1973, Broderson 1977, Newbold et al. 1980). For large rivers and mountain streams with steep banks (e.g., greater than 60%), a 70 m strip on each side of the watercourse is recommended.

c. Buffer strips should generally be left in an undisturbed, natural state but maintenance of open forest stands may be permissible to accommodate flood regimes in urban streams (Nunnally and Keller 1979) or prevent damage to bridges and other river structures with inadequate clearance (Morris et al. 1978).

D. Instream Cover

1. Principles and Guidelines

a. Instream cover features are important to fish because they provide spawning sites, protection from current or predators, or hiding places from which predators ambush prey. They also support important food resources and lead to changes in stream morphology that increase habitat diversity.

b. Extensive instream cover is essential in streams and rivers where viable sport and commercial fish populations are desired, including connected extra-channel reaches and habitats that provide spawning, rearing, and/or overwintering areas.

2. Recommendations

a. Instream cover structures such as logs or large boulders should also be maintained to provide habitat diversity in selected reaches of streams and rivers with unstable substrate.

b. In all other streams and rivers, some instream cover should be preserved to enhance fish species diversity and productivity. However, the amount of instream cover that is to be maintained in these channels should be weighed against potential conflicts with other stream uses (e.g., flood control and drainage).

E. Substrate

1. Principles and Guidelines

a. Substrate sorting and diversity along and across stream channels has a major influence on warmwater stream fish communities.

b. Stream substrates provide spawning sites, cover, and food producing areas.

c. Siltation is one of the most pervasive threats to ecological integrity in streams and rivers.

2. Recommendations

a. Natural substrate diversity and sorting must be preserved.

b. Fluvial attributes and processes leading to particle-size sorting and cleansing of substrates must be maintained.

c. Effective watershed conservation measures must be implemented to prevent excessive sediment inputs to stream channels.

F. Fluvial Characteristics

1. Principles and Guidelines

a. Spatial and/or temporal variability in a number of highly correlated fluvial characteristics, including stream size, gradient, current velocity, depth, and discharge exert a major influence on the structure of stream fish communities.

b. Severe floods and droughts especially have major destablilizing effects on stream fish communities.

2. Recommendations

a. Diversity in depth and current velocity must be preserved by maintaining stream size and gradient and channel morphology and pattern.

b. Increases in the extent and/or severity of discharge variability must be prevented by maintaining hydrologic characteristics of watersheds in as near a natural state as possible.

G. Watershed Management

1. Principles and Guidelines

a. The five major sets of variables that influence biotic integrity in streams and rivers (i.e., water quality, habitat structure, discharge regime, energy source, and biotic interactions) are directly or indirectly controlled by watershed characteristics, particularly those relating to land-use and the type and amount of vegetative cover.

b. Many running water fish populations depend upon different reaches of a drainage basin for various life history functions or as refuges during both normal and severe environmental conditions (Griswold et al. 1978).

c. Demands of modern society generally do not allow restoration or preservation of natural conditions throughout entire watersheds (Odum 1969, Karr and Dudley 1981).

d. A system of protected stream reaches serves as refuges during severe environmental conditions as well as important colonization reservoirs for the entire watershed (Luey and Adelman 1980).

e. Maintenance of ecological integrity in stream ecosystems requires an integrative view of the entire water resource system.

2. Recommendations

   a. A primary objective of aquatic resource management must be to preserve the integrity of entire watersheds.

   b. A compromise solution to opposing societal objectives should involve preservation of selected reaches of watersheds in their natural state while implementing to the greatest extent possible sound land and water conservation methods as well as mitigation techniques in other areas.

   c. Preserved areas in each watershed must include representative reaches of streams of all sizes and environmental conditions and must be protected from impacts that originate in modified regions of the watershed.

II. WATERSHED MODIFICATION AND STREAM RENOVATION GUIDELINES

A. General Principles and Guidelines

1. Stream and/or watershed modifications have major local, as well as wide-ranging impacts on water quality, habitat structure, discharge regime, energy source, and biotic interactions. These changes typically lead to degradation of biotic resources in running water ecosystems.

2. Although stream and/or watershed modifications are incompatible with the national mandate for preserving the integrity of our water resources, features of natural watersheds will continue to be modified to facilitate drainage of agricultural lands, flood control, navigations, and road and bridge construction.

B. General Recommendations

1. Effective soil and water conservation practices must be implemented in disturbed watersheds to (1) maintain a hydrologic balance in the watershed and (2) keep sediments and nutrients from destroying stream and river habitats (including extra-channel habitats).

2. All construction activities must include precautionary measures to minimize transport of dislodged sediment (especially from the land to running waters).

3. Any action that affects stream habitat must be considered in light of other local and regional activities.

4. Extensive straightening, widening, or deepening of channels should be unequivocally prohibited. Short-reach channel modifications not exceeding 500 m may be acceptable on a limited basis (e.g., for bridge construction and maintenance), providing adequate mitigation measures are taken to protect aquatic resources before,

during, and after the alterations. Cumulative modifications on any stream should not exceed 25% of the channel length.

5. At least some entire headwater streams should be preserved in their natural state in all stream systems. Decisions regarding which streams or reaches should be based upon the degree of potential land and water-use impacts and within the framework of a comprehensive watershed management plan.

6. All stream work should be planned to avoid damaging critical spawning and rearing areas and times of fishes.

7. Mitigation techniques including in-stream habitat improvement devices should be implemented when ecological recovery from past modifications is unlikely due to permanent loss or degradation of habitat.

C. Flood Prevention, Drainage, and Erosion Control

1. Principles and Guidelines

a. Flooding is a natural phenomenon.

b. A number of factors may lead to increased flood- and drainage-related problems.

c. Floodplain zoning is not universally feasible.

d. Attempts to engineer new channels that speed the flow of water downstream have catastrophic effects on stream and river ecosystems.

e. Land-use conversions and other watershed modifications alter hydrologic regimes. These changes disrupt stream equilibrium and often lead to an extended readjustment period during which considerable streambank erosion may occur.

2. Recommendations

a. Efforts to control flooding should involve careful floodplain zoning where practical.

b. The first step in any flood prevention, drainage, or erosion control program should be to identify the causes, including consideration of land-use conversions and/or massive watershed modifications that have disrupted stream equilibria and led to stream bank erosion (Table 6).

c. Where major flood damage is caused by stream blockages, selective clearing and snagging operations should be implemented. However, these activities, especially bank

TABLE 6. CLEARING AND SNAGGING GUIDELINES FOR REDUCING FLOOD DAMAGE IN SMALL WATERSHEDS (MODIFIED FROM MCCONNELL ET AL. 1980)

I. **Materials to be removed from the channel:**

- A. Log jams. Remove only those log accumulations that obstruct flows to a degree that results in significant ponding or sediment deposition.
- B. Other logs.
  - 1. Affixed logs. Isolated or single logs should not be disturbed if they are embedded, jammed, rooted, or waterlogged in the channel or the floodplain, are not subject to displacement by current, and are not presently blocking flows. Generally, embedded logs that are parallel to the channel do not cause blockage problems and should not be removed. Affixed logs that are trapping debris to the extent that could result in significant flooding or sedimentation may be removed. This may not be the best biology, but is a reasonable compromise among various societal objectives.
  - 2. Free logs. All logs that are not rooted, embedded, jammed or sufficiently waterlogged to resist movement by currents may be removed from the channel.
- C. Rooted trees. No rooted trees, whether alive or dead, should be cut unless:
  - 1. They are leaning over the channel at an angle greater than 30 degrees off vertical and they are dead or dying or have severely undercut or damaged root systems or are relying upon adjacent vegetation for support and it appears they will fall into the channel within one year and create a blockage to flows; or
  - 2. Their removal from the floodplain is required to secure access for equipment to a point where a significant blockage has been selected for removal.
- D. Small debris accumulation. Small debris accumulations should be left undisturbed unless they are collected around a log or blockage that should be removed.
- E. Sediments and soils. Major sediment plugs in the channel may be removed if they are presently blocking the channel to a degree that results in ponding and dispersed overland flow through poorly defined or nonexistent channels and, in the opinion of appropriate experts, will not be removed by natural river forces after logs and other obstructions have been removed.

II. Work Procedures and Equipment to Be Used

- A. Log removal. First consideration will be given to the use of hand operated equipment to remove log accumulations. When use of hand operated equipment is infeasible, the following restrictions and guidelines should be observed:
  - 1. Water-based equipment (e.g., a crane or winch mounted on a small, shallow draft barge or other vessel) should be used for removing material from the streams. A small crawler tractor with winch or similar equipment may be used to remove debris from the channel to selected disposal points.

TABLE 6. (CONTINUED)

2. When it can be demonstrated that stream conditions are inadequate for the use of water-based equipment, the smallest feasible equipment with tracking systems that minimize ground disturbance should be used. Larger equipment may be employed from non-wooded areas where cables could be stretched down to the channel to drag out materials to be removed.

3. Access routes for equipment should be selected to minimize disturbance to existing floodplain vegetation, particularly in the riparian zone. Equipment should be selected which requires little or no tree removal to maneuver in forested areas.

B. Rooted trees. Whether dead or alive, rooted trees selected for removal shall be cut well above the base, leaving the stump and roots undisturbed. Procedures for removing the felled portion will be the same as for other logs.

C. Log disposal--general. All logs or trees designated for removal from the streams or floodway shall be removed or secured in such a manner as to preclude their re-entry into the channel by floodwaters. Generally, they should be transported well away from the channel and flood-way and positioned parallel to the stream channel so as to reduce flood flow impediment. Where large numbers of logs are removed at one location (e.g., log jams), burning may be the best disposal technique. Burial of removed material should not be allowed.

D. Sediment blockages.

1. Access routes for equipment should be selected to minimize disturbance to existing floodplain vegetation, particularly in the riparian zone.

2. Material disposal and necessary tree removal should be limited to one side of the original channel at any given location.

3. To the maximum extent possible, excavating equipment should be employed in the channel bed to avoid damage to banks and vegetative cover.

4. Where feasible, excavated materials should be removed from the floodplain. If floodplain disposal is the only feasible alternative, spoil should be placed on the highest practical elevation and no material should be placed in any tributary or distributary channels which provide for ingress and egress of waters to and from the floodplain.

5. No continuous spoil pile should be created. It is suggested that no pile exceed fifty (50) feet in length or width and a gap of equal or greated length should be left between adjacent spoil piles.

6. Spoil piles should be constructed as high as sediment properties allow.

7. The placement of spoil around the bases of mature trees should be avoided where possible.

III. Reclamation Measures. All disturbed areas should be reseeded or replanted with plant species that will stabilize soils and benefit wildlife.

clearing and excavation, should only be allowed at specific locations where significant blockages occur. Furthermore, clearing to provide access to the stream should be minimized.

d. Stream and/or watershed renovation programs may be necessary in severely modified watersheds.

e. Accelerated erosion on the land surface requires an intensive watershed reclamation program emphasizing reestablishment of vegetative cover (Federal Water Pollution Control Administration 1970).

f. Stream renovation programs should be judiciously implemented to improve flow efficiency and promote bank stability in streams that are in the process of readjusting to man-induced changes in watershed hydrology. Channel straightening and changes in gradient must be avoided; but a channel can be "re-designed" so that it is adjusted to the discharge it is expected to convey.

g. Extensive streambank modifications should be discouraged but bank shaping can be effectively employed to improve flow efficiency, keep the bankfull discharge within the channel, and minimize bank erosion. Bank shaping should only be used to facilitate stream channel adjustments to modified discharge characteristics. In curved reaches cross-sectional areas may need to be enlarged to keep the bankfull discharge within the channel and reduce toe scour along concave banks. This can be accomplished by shaping the channel so that outside banks of meander bends have steeper slopes than the inside banks. This mimics natural channels and promotes deposition of sediment along the inside bank (Keller and Hoffman 1977) rather than between bends where excessive sedimentation can lead to backwater effects. An inclination of 3:1 or less on inside banks and 2:1 or steeper on outside banks can be used as a general guideline (Table 7), but the type and texture of material comprising channel banks is a major factor governing the choice of an erosion resistent bank slope (Klingeman and Bradley 1976). Proper alignment of streambanks is also of critical importance in maintaining flow efficiency and preventing erosion. Extreme local channel constrictions and expansions should be avoided. Alignment at bends should be smooth and gradual with an entry angle less than 15-25 degrees (Klingeman and Bradley 1976). Along straight reaches, emphasis should be placed upon reshaping false points and other bank irregularities.

TABLE 7. SUGGESTED BANK SLOPES FOR STREAM BANKS WITH DIFFERENT SOIL TEXTURES (from Klingeman and Bradley 1976.)

Soil Texture	Bank Slope (horizontal: vertical)
Heavy clay	1.25 - 2: 1
Medium-textured	1.50 - 2: 1
Sand, gravel, cobbles	2 - 4: 1

h. Stabilization of disturbed and/or eroding streambanks can usually be accomplished by "natural" means; that is, by establishing vegetative cover on streambanks and employing sound land management in the watershed.

i. Structural methods of erosion control such as riprap, revetment, retards, and jetties should generally only be used to facilitate and/or supplement vegetative bank stabilization.

D. Navigation and Bridge Construction

1. Principles and Guidelines

a. Periodic dredging is necessary to maintain navigation channels in large rivers.

b. Minor stream modifications are required for bridge construction.

2. Recommendations

a. Better land management practices should be implemented to reduce the need for navigational dredging.

b. Dredging operations should include use of silt curtains or turbidity barriers (IDOC 1981). Overdepth navigational dredging should be restricted.

c. Fish habitat must be protected during spoil disposal. Open water disposal should be prohibited.

d. Recommendations developed by the Great River Environmental Action Teams I and II concerning navigational modifications of rivers should be adhered to (Vanderford 1980).

e. Recommendations developed by the Dept. of Transportation for reducing environmental impacts of bridge and culvert installation should be adhered to (FHWA 1979, Shen et al. 1981). Open-bottom culverts are preferable. All culverts should be designed to prevent downstream bed or bank erosion and allow fish passage during low and high flows (IDOC 1981).

E. Establishing Bank Vegetation

1. Principles and Guidelines

a. The effectiveness of bank vegetation varies with size and slope of the stream, frequency and duration of floods, climate, productivity and inherent erodibility of the soil materials along the stream edge, texture and transport rates of bed material, and land use (Parsons 1963). Vegetation is perhaps most effective in preventing streambank erosion in smaller streams with moderate to low width/depth ratios.

b. Factors to consider in choosing vegetation for stabilizing the face of stream banks include its strength, resilience, vigor, root system development, initial growth rate, ability to reproduce, and resistence to disease and insects (Parsons 1963, Klingeman and Bradley 1976).

2. Recommendations

a. Techniques to insure vegetative growth on a planted slope include addition of topsoil on sandy or gravelly slopes, cultivation, fertilization, and mulching.

b. Temporary auxiliary protection may be needed, particularly on lower portions of banks when flooding may hinder or prevent establishment of a vegetative lining. On small streams with stable beds, 15 to 45 cm thick brush mats provide effective temporary bank protection as well as a dense mulch for developing vegetation (IDOC 1981).

c. Quick establishment of grassy vegetation provides a good soil-binding matrix and may facilitate development of stable overhangs which provide fish cover (White and Brynildson 1967). Brush and other types of vegetation take longer to become established, but provide a larger buffer zone between flowing water and the soil surface. Woody vegetation also provides shade which is extremely important in small warmwater streams. Hence, establishment of brush and large woody vegetation should accompany or immediately follow grass plantings. Effective mixtures of woody and herbaceous vegetation should include dense stands of shrubs or shade tolerant grasses in a less dense stand of trees. Isolated, bush vegetation is undesirable because it may obstruct flow and cause destructive water velocities in its immediate vicinity (Parsons 1963). Willows (Salix) appear to be the most amenable and effective tree species for protecting banks of small streams. They are easy to establish from cuttings, thrive in wet soils, and with periodic basal pruning produce a continuous "root revetment" that affords more than adequate streambank protection as well as abundant fish cover (White and Brynildson 1967). Although the value of willow leaves and twigs in trophic-energetic relationships in streams is not sufficiently known to recommend its widespread propagation along disturbed channels, this potential drawback can be avoided by mixed-tree plantings.

d. Management after treatment is a key to vegetative streambank stabilization (Lines et al. 1978). Well-vegetated buffer strips must be free from cultivation or excessive use by livestock on both the bank slope and top of the bank to prevent surface runoff on adjacent land from causing sheet or rill erosion on the face of the bank.

e. Other means of bank protection may be required when excessive toe scour is not amenable to vegetative stabilization. Combination of vegetative and structural stabilization can sometimes be implemented to treat critical areas without serious environmental consequences.

F. Structural Solutions to Habitat Improvement

1. Principles and Guidelines

a. Structures created to benefit aquatic organisms often do not function well because they are not carefully matched to the physical and biological dynamics of the stream.

b. Careful evaluation of the needs of each stream as an individual dynamic system creates habitat conditions that are both long-lasting and a positive benefit to the aquatic biota.

c. Biologists, hydrologists, and engineers must cooperate in evaluating the needs of the stream in question from both biological and physical dynamics perspectives.

d. The overall effect of habitat improvement devices is to increase habitat diversity, whether by directly providing shelter, or by altering flow, channel morphology or substrate composition (Swales and O'Hara 1980).

2. Recommendations

a. Considerable care should be exercised in the selection of structural solutions to habitat problems.

b. Submerged log and brush shelters can provide cover if they are securely fastened to the streambank and positioned to avoid obstructions or damming the flow.

c. Judicious placement of large rocks within a stream channel is probably the simplest and most stable in-stream device for improving fish habitat. Large rock can increase habitat diversity by diverting the flow (Calhoun 1966), as well as provide nesting areas and cover (Patterson 1976, Griswold et al. 1978).

d. Low dams of rock or logs are one way of recreating pool and riffle habitats and increasing the diversity of flow conditions and substrate types. However, it is important to make the dam small enough so that it is drowned out at high discharges, and, hence, allows fish passage during migration periods.

e. Current deflectors, another means of altering channel morphology, guide flow through a constricted channel leading to higher current velocities, removal of deposited sediment, and increased thalweg depths. The stream bed eventually forms a pool and, downstream of this a riffle. Alteration of deflectors from one bank to the other conducts the current on a sinuous path resembling natural channel flow.

f. The most common structural method for stabilizing a severely eroding streambank is to armor it with rock riprap. Riprap must be wide enough to insure that it is tied into stable banks and low enough to adequately protect the lower banks and toe slope. Adverse aesthetic effects can be minimized by initially riprapping only those areas that are highly susceptible to erosion and later adding supplemental stone to locations where scour is evident (Nunnally 1978). Application of soil to riprap followed by seeding promotes rapid establishment of vegetative cover. Submerged riprap appears to benefit fish by providing cover, spawning sites, and substrate for food resources (Patterson 1976).

g. The use of retards and jetties to facilitate establishment of a vegetative lining has also been successful. However, these structures should only be used on medium to large rivers where (1) they are necessary to prevent undermining of roads or bridges and (2) potentially erosive flows will not be directed toward opposite streambanks. Jetties are built perpendicular to the flow and upstream of an eroding bank so that slack water is created at the erosive area. Jetties have proven to be particularly compatible with high density plantings of woody vegetation (Lines et al. 1978). Retards are built parallel to an eroding bank and function by deflecting the flow. Deep scour holes are commonly created near both jetties and retards and appear to provide excellent fish habitat, especially during low flow periods (Witten and Bulkley 1975).

h. Where adequate land drainage or flood control cannot be attained by stream renovation, levees, pilot channels, and floodways should be considered.

i. Levees can be effective in preventing periodic inundation of land adjacent to water courses. However, planners should keep in mind the importance of that inundation as a natural phenomenon, essential for maintaining biotic integrity in some environments (especially large river - wetland ecosystems). Moreover, levees may lead to bank erosion and channel scour within the protected area, as well as increased upstream and downstream flooding. These problems can be minimized by including a portion of the floodplain between the levee and stream channel (IDOC 1981) or by restricting but not eliminating overbank flows (e.g., with notches or culverts), thereby preserving the integrity of critical floodplain habitats.

j. Pilot channels (Keller 1975) are undisturbed, natural streams that are contained within a larger, man-engineered, flood-control channel while floodways are auxillary, high-flow channels that carry floodwaters around a protected area (IDOC 1981). The high-flow channel is generally straight and is designed to remain dry until the water stage in the natural channel reaches a predetermined level. Beyond this stage, flood waters are carried in the floodway until it joins the main channel downstream. Although pilot channels and floodways appear to be fairly good compromise solutions, they are still relatively new and untested innovations. Therefore, they should only be implemented after careful evaluations are made on a case by case basis regarding their potential utility and environmental impacts. More detailed information on the use of levees, pilot channels, and floodways, can be found in USDA (1971, 1975, and 1977) and IDOC (1981).

k. Recent attempts to mitigate the impact of structures (dikes) used for bank stabilization and navigation purposes in large rivers have the objective of reducing permanent land accretions behind the structures and, thus, encroachment upon the flood carrying capacity of the river and elimination of fish and wildlife habitat diversity (Burke and Robinson 1966). For example, "notches" can be cut in existing dikes to allow water to flow through the structure and develop side-channels and submerged sand bars. Lowering the height of newly installed dikes is effective in producing a deep hole immediately behind the structure and a submerged bar further downstream. Rootless structures are another design improvement. These are dikes that are constructed perpendicular to the flow without being tied to the bank thus allowing water to flow between the structure and the bank and leading to the development of small sand bars downstream. Preliminary observations indicate that a number of large river fishes such as flathead catfish, freshwater drum, and blue sucker appear to prefer the fast water provided by these structural modifications. During low flow periods fish concentrate in the deep scour holes near the structures, and the shallow sand bars provide nursery areas for young fish.

l. Where large river environments have been modified by navigation dams, fish habitat can be improved by artificial opening or closing of side channels that lead to backwater areas (Fremling et al. 1976, Nielsen et al. 1978, Fremling et al. 1979, Claflin and Rada 1979). However, all possible effects of these modifications must be thoroughly evaluated before implementation. For example, by increasing inflows of fresh, oxygenated water into the backwaters, the opening of new side channels can increase overwintering habitat as well as open previously stagnant areas. On the negative side, the increased inflow of water and accompanying sediment may destroy weed beds that serve as important spawning, nursery, and feeding areas for many riverine fish species. Similarly, while artificial closing of side channels may decrease transport of sediment into backwaters and improve the hydraulic efficiency of the main channel, they may cause severe oxygen depletion problems in cutoff areas. In most cases, the negative effects of side channel openings or closings can be avoided if they are strategically located, but channel modifications should be avoided when the existing backwater fishery shows no signs of degradation.

m. A detailed review of common stream habitat improvement devices and techniques can be found in White and Brynildson (1967) and Swales and O'Hara (1980).

III. INNOVATIVE SOLUTIONS - RECOMMENDATIONS FOR AGRICULTURE

Since agriculture impacts the largest portion of midwestern streams and since we call attention to weaknesses in several existing programs in an early section of this report, we feel compelled to call attention to programs that have been suggested to circumvent present problems.

A. General Principles

1. Innovative solutions must reconcile the financial viability of farming and farmers with the need for more enlightened management of water resources.

2. Since it is not possible to maximize several goals simultaneously, a careful integration of societal objectives can only be accomplished through cooperation of all segments of society.

3. A more efficient, conservation minded approach might merge price support, conservation cost sharing, and related USDA programs with EPA nonpoint pollution programs. Each program preserves farmland (soil) while improving water quality; in combination their benefits increase even more (see specific suggestions below).

B. Regulations

1. Although it is desirable to avoid regulation, the fact remains that some farmers abuse their soil and adjacent waters under a purely voluntary program.

2. One or two abusers of the resource can produce major damage despite sincere efforts of their neighbors.

3. Regulation phased in over a period of years (less than one decade) seems the best approach with society at large sharing the "cost" of regulatory measures with the landowner.

4. Both positive (e.g., cost sharing and tax incentives) and negative (e.g., fines for excess erosion) incentives could be included in regulatory programs.

5. Violations might carry a double penalty with the abuser paying a fine in addition to repayment of cost-sharing funds and technical-assistance costs.

6. Land owners that follow sound conservation practice need not fear regulation; abusers of soil and water resources should fear regulation.

C. Technical Assistance

1. Federal and state supported conservation programs might reorder their technical assistance to conservation objectives from present programs dominated by production-oriented objectives.

2. The technical base of these programs might be expanded to include a broader background by incorporating a wider array of natural resource objectives. Policy decisions must be more broadly based for the long-term betterment of American Society.

3. With this expanded breadth, land management plans would be agreements between society (through its governmental organization) and individuals or groups of landowners to implement programs necessary to protect soil and water resources as well as insure long-term production of food and fiber.

D. Cost Sharing Programs

1. Under cost-sharing programs society agrees to pay part of the cost of implementing conservation practices.

2. These programs may involve short-term net loss to the landowner but long-term gain to society through their positive impact on soil and/or water conservation.

3. Required maintenance agreements (see cross-compliance below), as well as transfer of agreements to new owners (i.e., should land be sold), might be included.

E. Low Interest Loans

1. Availability of low interest, federally-subsidized loans, either general loans for normal operations or loans to allow implementation of conservation practices, might be tied to a mandatory, comprehensive, conservation program.

F. Tax Incentives

1. In a positive sense, a tax law could be designed to give farmers a tax break if they reduce their erosion losses and other impacts on water resources to reasonable levels (e.g., below T levels). Alternatively, a flat rate (price) per ton of soil saved per year might be used, but only farmers on problem lands should receive this benefit.

2. Unfortunately, positive stimuli are likely to be insufficient to attain societal objectives regarding land and water resource conservation. Thus, a substantial negative tax might be levied on property owners when erosion levels on their land has an adverse impact on water resources.

3. A system of export taxes might also be developed to provide funds to mitigate resource degradation resulting from higher production.

4. The existing tax structure for use of reservoir and stream water could be reformed to more precisely reflect the real value of these resources. At least some of the proceeds of these taxes could be used to control erosion, protect stream corridors, and otherwise enhance water resources.

5. The tax code could be modified to allow investment credits for conservation programs (with long-term contracts) and heavier taxation for land developments that degrade water resources (e.g., wetland drainage, groundwater contamination, stream dewatering).

G. Cross Compliance

1. Federal and state subsidy programs (commodity price supports), low-interest loans, cost-sharing, and crop insurance) could be coupled with soil and water conservation efforts such that attainment of specific conservation goals is a precondition for eligibility.

H. Selective Application

1. Since funds for water resource improvement will always be limited, those funds should be targeted where they do the most good for society. Not all farmers are entitled to these funds just like all farmers are not eligible for disaster relief in any year.

2. Selective application involves protection of all factors, including physical habitat parameters, that are necessary for preservation of biotic integrity in running water ecosystems.

I. Classified Streams

1. The practice of setting aside areas for protection is well established. Unique natural areas or historical sites have long been protected from development to enhance their long-term value to society.

2. Since headwater streams play an especially important role in determining water resource quality throughout watersheds, set-aside programs might emphasize a classified headwater approach.

3. Implementation mechanisms might include long-term leases or outright purchase, invoking the power of eminent domain where water resource conservation is particularly critical.

J. Miscellaneous

1. The "Green Ticket" program of the National Association of Conservation Districts includes many of the advantages of programs described here as they improve the long-term profitability of American agriculture while implementing needed conservation measures.

2. These programs should be concentrated on land where treatment of the smallest possible area (at the lowest economic cost) yields the greatest benefit to society.

3. Resource conservation programs should include strong incentives and be coupled with stronger state and local leadership involving all segments of society.

4. Our long-term interests require more effective protection of land-based resources with judicious enforcement of a palatable legal and regulatory program.

5. Without a program that accomplishes the above objectives, we face catastrophic declines in food and fiber production, as well as irreparable degradation of land and water resources.

K. Model Legislation

The United States is not the only country trying to resolve water resource problems. The major Venezuelan law relating to soil and water resources--"Ley Forestal de Suelos y Aguas", and regulations promulgated after its passage are, at least in part, model legislation for protection of these resources in the United States. The law calls for development of a soil classification system based on slopes, level of erosion, soil fertility, and climatic factors. This system is to be used to maintain the physical integrity as well as productive capacity of soils. It allows the Ministry of Agriculture to enforce these principles on private land, at the expense of the owner. It also empowers the Ministry to provide technical and financial assistance to landowners when that is in the best interest of those concerned.

The Venezuelan agencies responsible for drafting of that law were clearly aware of the principles involved in protection of the many resources associated with the land. For example, to reduce erosion and soil deterioration, the regulations promulgated after passage of the law make rather detailed provisions for protection of soils. Slopes of 0-15% are suitable for cultivation of all classes of crops, but, to protect the soil, it is still necessary to control erosion. Slopes of 10-35% are only suitable for establishment of carefully cultivated annuals and perennials. Slopes in excess of 35% are suitable only for establishment of selected crops like coffee and perennial fruits. Slopes in excess of 10% must be sowed perpendicular to the slope. Slopes of 15-25% must have grass terraces at least 1.5 m wide at maximum distances of 30m apart along the slope. On slopes of 25-35%, grass terraces must be at least 3.5 m wide with distances no greater than 10 m between terraces. Further, activities involving destruction of vegetation on land in the public domain as well as on private property can only be undertaken with prior authorization of the Ministry of Agriculture.

L. Summary

A more effective program to protect the physical habitat of warmwater streams is both possible and practical. It should begin with judicious enforcement of a palatable legal and regulatory program. A more effective system is essential if we are to avoid catastrophic declines in food and fiber production, as well as irreparable degradation of land and water resources. A more enlightened program must be based on:

1. Sound knowledge of the dynamics of interacting soil and water resource systems;

2. The effects of human activities on these systems;

3. A governmentally funded program of technical assistance

to deliver this knowledge;

4. An array of incentive programs to insure selective application of that technical assistance, and

5. A background of regulatory mechanisms that can be applied when voluntary and incentive programs are not successful.

IV. EXPECTED BENEFITS

A more integrative approach to the maintenance of physical habitat characteristics in warmwater streams can be expected to reverse the trend toward degradation of water resources through:

a. Improved water quality and quantity.

b. Improved fishery systems and other aspects of biotic integrity, including terrestrial wildlife associated with riparian environments.

c. More effective and efficient processing of natural and man-induced organic inputs to running waters.

d. Spin off advantages to soil conservation.

e. Reduced sedimentation of channels and reservoirs from land and channel sources.

f. Decreased cost of channel construction and maintenance activities.

g. Reduced downstream flooding.

h. More intensive agriculture with reduced effects on aquatic ecosystems when land management systems are not feasible.

i. Increased recreational opportunities.

j. More cost effective attainment of legislative mandates for water resource systems.

SECTION 3

DEVELOPMENT OF PHYSICAL CHARACTERISTICS OF STREAM CHANNELS

For many years decisions on the management of running water resources were made by hydraulic engineers on the basis of hydrological processes. In recent years knowledge of the influences of biological dynamics have increased and a cadre of spokesmen have become more articulate at communicating the significance of those dynamics. The result is emergence of a more integrative perspective on goals for management of running water resources. In this section we discuss the determinants of physical habitat in a natural stream channel. In section 4 we outline the role that this habitat plays in determining the biological communities of a stream.

Our intent is not an exhaustive treatment of watershed hydrology, a task that would require volumes. Rather, we hope this short synthesis will serve as an introduction for those who are unfamiliar with the role of hydrology in natural drainage systems. More substantial presentations of this background material are available in the cited literature (particularly Leopold, et al. 1964, Dunne and Leopold 1978, Heede 1980).

WATERSHED CHARACTERISTICS AND WATER-SEDIMENT DISCHARGE

The physical structure of stream channels reflects the geology, geomorphology, biology, climate, and hydrology of a drainage basin (Schumm 1971). Drainage patterns and channel configurations are ultimately constrained by the nature of the parent material (particularly its resistence to erosion) and historical factors such as glaciation, uplift, and faulting (Marzolf 1978), but are largely shaped by water-sediment discharge regimes.

Hydrologic development of stream channels is mediated by climate (particularly precipitation patterns), topography, soil properties, land-use, and vegetative cover (Dunne and Leopold 1978). Interactions among these factors determine the primary source of stream flow which, in turn, influences a number of drainage and channel characteristics. In arid and semi-arid regions and watersheds that have been disturbed by intensive agriculture or urbanization, a large part of the annual precipitation budget is delivered to stream channels as surface runoff during storm events. In humid regions with deep, permeable, well-drained soils, most rainfall penetrates the soil and reaches stream channels primarily through subsurface flow.

By regulating the infiltration capacity of soils, the type and amount of vegetative cover and hence, land-use, often exert primary control over relative rates of surface runoff and groundwater inflow. Forest soils, for example, may absorb 50 times as much water as cultivated fields and pastures (Auten 1933). Lower water absorption by field soils is partially due to compaction of bare surface soil and sealing of soil pores during rainfall (Lowdermilk 1930). The porosity of forest soil is preserved by the protective covering of leaf litter and by the granular soil structure that results from high humus content (USDA 1940). The presence of vegetation and litter may also mechanically retard runoff by reducing the velocity of surface movement; thus, more time is allowed for infiltration (Musgrave and Free 1936). Infiltration and water-holding capacities of soils are also influenced by the extensiveness of plant root systems (USDA 1940).

Temporal Variation in Flow

Due to prevailing rainfall patterns over the continental United States, discharge regimes of most warmwater drainages are typically characterized by sustained normal or high flows during winter and spring and relatively low flows in summer and early fall. However, due to the stochastic nature of precipitation events, this overall pattern may be highly variable within seasons as well as between years.

Discharge variability in stream channels is also influenced by the primary source of flow. Headwater streams with groundwater flow have relatively constant and permanent discharge, while runoff-fed streams have highly variable flow (Horowitz 1978). Discharge variability decreases in downstream sections but seasonal extremes are still common (Matthews and Hill 1980).

As discussed above, the source of stream flow and associated discharge variability is determined by watershed (particularly vegetative) characteristics. During heavy rains, a proportion of the water that falls upon watersheds with deep soils that are covered with vegetation or a mat of litter is added to the groundwater supply and rarely reaches stream channels in time to add to the crest of floods. Hence, although the relative amount of precipitation that penetrates the soil surface varies with the timing, frequency, and type of rainfall event, flood hydrographs are generally dampened in well-vegetated watersheds by reduced surface runoff.

Despite higher evapotranspiration losses (Dunne and Leopold 1978), low flows are also less extreme in well-vegetated (particularly forested) watersheds. This is primarily due to infiltration and groundwater storage of precipitation and its subsequent prolonged release to stream channels (Bode 1920, Zon 1927). Low flows are also moderated by lower evaporative losses from the water surface in stream channels with extensive nearstream vegetation.

Sediment Load

Factors that affect sediment movement from the land surface to stream channels include climate, drainage area, soils, geology, topography, vegetation, and land-use (Dendy and Bolton 1976, Dunne and Leopold 1978). However, vegetation may assume overriding importance, so that the denser the vegetative cover the lower the rate of erosion (Dunne and Leopold 1978). Vegetation reduces transport of sediment from the land surface to stream channels in two ways. First, vegetative cover reduces dislodgement of soil particles by dispersing the energy of raindrop impact and by the soil binding forces of its root masses (Copeland 1963). Secondly, by retarding overland flow, vegetation reduces sheet and rill erosion and promotes deposition of eroded sediment before it reaches stream channels (Kao 1980).

Sediment discharge in streams is also influenced by bed and bank erosion, particularly during high flow periods. The magnitude of channel erosion can vary significantly within as well as between watersheds (Dudley and Karr 1978). The outside banks of bends, particularly sharp bends, are the most likely place for erosion to occur, but strong scouring currents may be directed toward banks that are opposite channel bars and irregular bank lines (Klingeman and Bradley 1976). Instream structures such as fallen trees and log jams may also cause channel erosion by deflecting the flow toward the banks (Sachet 1977, Nunnally and Keller 1979).

WATER-SEDIMENT DISCHARGE AND CHANNEL STRUCTURE

Although clearly mediated by characteristics of the drainage basin, the energy flux associated with discharge of water and sediment controls the development of most surface stream channels (Curry 1976). As water flows through the system it is transformed from potential energy to kinetic energy. Most of this kinetic energy is dissipated as heat along the channel boundaries (Mackin 1948); but the remaining portion forms the stream network by carving channels through erosion and transportation of sediment. In accordance with the second law of thermodynamics, the most probable distribution of energy expenditure within geomorphic systems is one in which entropy is maximized (Leopold and Langbein 1962). Expansion of this principle suggests that all aspects of a drainage system, including variability among the hydraulic parameters (Langbein 1964, Yang 1971a, Stall and Yang 1972, Cherkauer 1973), as well as the development of pools and riffles (Yang 1971b), various channel patterns (Langbein and Leopold 1966, Yang 1971a,c) and even the form of the stream network (Yang 1971a), represent adjustments of the rate of energy expenditure within hydrologic and geologic constraints. The end result is the evolution of a "dynamic equilibrium" characterized by a stream channel morphology that efficiently distributes the energy flux required by the basin's water-sediment discharge regime.

The evolution of a dynamic equilibrium in streams occurs within an "open" system in which there is a continuous inflow and outflow of materials. Streams in equilibrium adjust to variation in discharge and sediment concentration, while maintaining their form and profile. These adjustments are made primarily by the hydraulic variables (i.e., depth, velocity, and wetted perimeter) but may include minor changes in bed form. Although channel morphology remains stable under these conditions, it is important to recognize that these parameters are shaped by long-term water-sediment discharge characteristics of the watershed.

Hydraulic Adjustments

At a given cross-section, width, mean depth and mean velocity of flowing water generally increase with an increase in discharge (Leopold, et al. 1964). However, the manner of hydraulic adjustment is constrained by channel geometry. In narrow channels, wetted perimeter changes very little with increased discharge, but velocity and depth increase. In wide channels, the rate of increase by the wetted perimeter is large, while velocity and depth change only slightly. Velocity distribution also varies with different width-to-depth ratios. In narrow and deep cross-sections, high velocities extend closer toward the sides of the channel than in broad, shallow sections. Moreover, in narrow, deep channels, velocities close to the sides are as high or higher than those close to the bottom, whereas in wide, shallow channels, velocities are higher on the bottom (Lane 1937).

By altering flow resistence (Langbein 1964, Simons and Richardson 1966), changes in bed configuration play a major role in hydraulic adjustments to variation in water-sediment discharge (Heede 1980) and thus represent an important mechanism by which streams maintain an equilibrium (Leopold, Wolman, Miller 1964). Changes in bed configuration may range from subtle modifications of dunes and bars to channel scour and fill.

Sediment Transport Dynamics

By facilitating hydraulic adjustments while maintaining a balance between channel erosion and deposition, sediment transport dynamics play a pivotal role in stream equilibrium. Sediment transport rates are primarily a function of water discharge and slope, and vary among particle sizes (Lane 1955a). Stream sediment loads consist of two fractions (Dunne and Leopold 1978). Suspended load or wash load is made up of fine sediment grains that are lifted up and carried for long distances within the main thread of flow. Larger sediment particles that are rolled or dragged along the bottom constitute bed load. Differences in the sediment transport capacity of these fractions combined with spatial variation in stream gradient (see below) result in natural substrate sorting and heterogeneity in stream channels.

Differences between sediment transport capacity and actual sediment load lead to nonuniform flow of sediment and an imbalance between deposition and scour (Lane 1955b). The accumulation of fine sediments in stream channels is dependent upon the magnitude of preceding storm and associated runoff events, groundwater and throughflow contributions, and especially the relative timing of sediment and water discharge peaks (Costa 1977). In small drainage basins peak sediment concentrations usually occur before peak discharge (Dragoun and Miller 1966, Guy 1964). Consequently, small channels are cleared of fine sediment. However, if rainfall is of low intensity and runoff amounts are small, water and sediment concentration peaks can occur together (Vanoni 1975) and result in accumulations of silt and clay deposits as discharge returns to normal levels.

Substrate characteristics of stream channels change with seasonal variation in flow (deMarch 1976). Except for depositional areas, substrates are generally cleansed of fine particles by spring high flows; however, as discharge decreases during summer, substrates become covered with silt and sand. Sediment transport during summer months is also hindered by a reduction in viscosity as water temperatures increase (Colby 1964).

Channel Geometry

Channel width is primarily determined by the long-term discharge regime of the watershed, and in particular, the magnitude and frequency of high flow events (Wolman and Miller 1960). However, it is also affected by the nature of the sediment load. Like bed fill and scour, an equilibrium exists between bank erosion and deposition of sediment transported by the channel (Shumm 1971, Einstein 1972). Streams with coarse sediment loads are generally wider and have more erosive banks than channels with relatively high suspended sediment loads and banks composed of high percentages of silt and clay (Heede 1980). Similarly, where tributaries introduce large suspended sediment loads, channel width decreases in the receiving stream; when large sand loads are introduced, channel width increases.

Channel slope is relatively stable in streams at equilibrium, but is also regulated by water-sediment discharge. As discharge increases downstream, slope generally decreases so that the longitudinal profile of a river is concave. However, this decrease in slope is also related to a decrease in sediment particle-size (Schumm 1971, Leopold, et al. 1964). Streams adjust their slope to maintain a nondeposit and nonscour channel and the gradient required for transport decreases with a decrease in sediment particle-size and/or load (Mackin 1948, Yang 1971c).

Variation in channel slope also occurs along streams in the form of alternating sequences of pools and riffles, that are consistently spaced between five and seven channel widths apart (Leopold, et al. 1964, Keller and Melhorn 1978). Pools and riffles are commonly found in all streams in which the bed material is larger than coarse sand, but are most highly developed in medium-gradient gravel bed streams. Within a given reach, a riffle is characterized by greater than average steepness, while a pool has less than the average slope (Langbein and Leopold 1966).

The development of riffles and pools appears to begin with the formation of asymmetric shoals which slope alternately toward one bank and then toward the other (Keller 1972). This causes a convergence and divergence of flow that leads to scouring of the incipient pool and deposition on the incipient riffle below. Deposition leads to a steeper slope and hence a higher velocity gradient on the incipient riffle. Once the difference in velocity gradient between a pool and adjacent riffle is established, differences in pressure between sediment grains depresses the bed surface at the pool and raises it at the riffle to form a concave-convex profile (Yang 1971b). Differences in velocity gradient also lead to sorting of sediment grains such that large gravels collect at riffles and finer materials are deposited in pools. As the processes of dispersion and sorting continue, the difference between the water surface slope of a riffle and that of its adjacent pool increases.

Despite the presence of these zones of erosion and deposition, substrates in channels with pools and riffles are more stable than equivalent channels with uniform cross-sections. During low and medium flow conditions, unit stream power, the product of water surface slope and velocity and hence a measure of sediment transport capability, is 23 - 26% lower in a stream segment with pools and riffles than in a comparable channel without pools and riffles (Stall and Yang 1972). However, the hydraulic differences between riffles and pools that lead to this reduction in unit stream power are highly dependent upon flow conditions. As discharge increases, water surface slope in pools increases while water surface slope in riffles decreases. A threshold is eventually crossed where the bottom velocity of pools exceeds that of riffles (Keller 1971). Beyond this point unit stream power does not appear to be affected by pools and riffles, but the velocity reversal during these high channel forming flows leads to the scouring of pools and deposition of coarse material on riffles. Hence, pools scour at high flow, and fill at low flow, whereas, riffles fill at high flow and scour at low flow (Nunnally and Keller 1979).

Channel Pattern

Channel pattern also influences hydraulic characteristics of streams. Increased sinuosity (the ratio of total length of stream along its meandering course to downvalley distance), for example, leads to greater variation in depth and current velocity (Zimmer and Bachmann 1976). Long, straight reaches are rare in unmodified streams and even where a channel is relatively straight, the thalweg or line of maximum depth wanders back and forth from one bank to the other. As noted above, this is due to the presence of asymmetric shoals, which in addition to leading to development of riffles and pools, are also important in the formation of meanders. In meandering streams, pools are found at the zone of greatest curvature opposite point bars, and riffles are located at inflection points between adjacent bends. The depth of pools opposite point bars is inversely related to the radius of curvature of the bend (Heede 1980). Radius of curvature and meander length are highly correlated with channel width, while the amplitude of a meander loop appears to be determined by the resistence of the stream banks to erosion (Leopold, et al. 1964). Sinuosity tends to increase in downstream reaches (Stall and Yang 1972).

Vigorous crosscurrents near the bed in a bend can transport considerable quantities of bed material toward the convex banks and appear to be at least partly responsible for point bar formation. The highest velocity in a meandering reach tends to be located near the concave bank just downstream from the axis of the bend. This slight lack of congruence of streamline curvature with bank curvature leads to a tendency for the locus of point bar deposition to occur downstream from the axis of the bend. Because of this, river curves tend to move downvalley over time. They also tend to migrate laterally as the stream erodes its channel on the outside bends and deposits on inside point bars. Due to added flow resistence introduced by the curve, less energy is available for sediment transport (Nunnally 1978). As a result there is little or no net change in sediment discharge through the reach. In fact, in meandering sections with pools and riffles, sediment transport may be over 20% lower than in straight channels (Karr and Gorman 1975).

The dynamic character of natural meandering rivers often results in the formation of temporary side channels that are separated from the main channel by a small island (Ellis et al. 1979). Side channel habitats may range from fast-flowing riverine types to those with nearly static waters. Sediment deposition during high river stages coupled with encroachment of island and mainland vegetation ultimately results in a balance between the formation and elimination of side channel habitats (Simons et al. 1975).

A braided channel pattern tends to develop in streams and rivers with high sediment loads and easily eroded banks. Streams with erodible bank materials have high width to depth ratios and as a result, insufficient velocities to carry a large sediment load. Hence, part of the sediment (particularly the coarser fractions) is deposited as a central bar(s) that diverts the flow through smaller but steeper channels. Since these channels are more capable of maintaining a balance between sediment inflow and outflow, they tend to be more stable under these conditions than a single wide and shallow channel.

RIPARIAN ENVIRONMENT AND CHANNEL DYNAMICS

Streambank vegetation affects both channel morphology and hydraulic characteristics by (1) reducing the effective size of the channel (2) increasing hydraulic resistence and (3) increasing the resistence of banks to erosion (Nunnally 1978). Because of the greater resistence of vegetated banks, vegetated channels tend to be narrower and have steeper slopes than non-vegetated channels. Vegetation stabilizes streambanks by (1) binding soils (2) reducing water velocities at the soil surface (3) inducing deposition of sediment and (4) acting as a buffer against transported debris (Parsons 1963, Nunnally and Keller 1979). Trees and brush afford more protection to streambanks than short or low-lying vegetation (Klingeman and Bradley 1976). Grasses are most effective during the growing season and when they are young, sturdy, and resilient.

By altering water flows and sediment transport dynamics, inputs of large organic matter from the riparian environment may also have significant effects on stream channel structure. For example, in sand-bottom streams, deep holes are commonly scoured near fallen trees and other large woody debris, creating relatively permanent pools in an otherwise uniform and unstable habitat (Hickman 1975, Mendelson 1975). In high gradient, bedrock streams, habitat diversity is enhanced by pools and waterfalls that are formed by entrainment of sediment behind debris dams (Triska and Cromack 1979, Bilby and Likens 1980). However, by diverting water flows toward stream banks, channel obstructions may also lead to large local increases (up to 50%) in channel width (Keller and Swanson 1979). Moreover, accumulations of debris may cause channel modifying backwater effects upstream (e.g., development of meander cutoffs).

Nearstream vegetation also indirectly influences the physical structure of small streams by providing shade. In addition to having a major impact on temperature regimes of small streams (Brown and Krygier 1970, Brazier and Brown 1973), shade from riparian vegetation limits the growth of aquatic flora (Jahn 1978, Kern-Hansen and Dawson 1978). In the absence of shade, heavy growths of aquatic macrophytes can constrict the flow of water and result in scouring of the stream bottom, deepening of pools, and undercutting of banks (Hunt 1979).

Since water temperatures influence oxygen concentrations and availability of dissolved nutrients, shade provided by nearstream vegetation plays an indirect role in regulating these parameters. In fact, due to its pivotal position at the land-water interface, riparian vegetation can play a major role in determining water quality. This is particularly true in agricultural watersheds where nearstream vegetation can effectively filter sediment and attached nutrients from surface runoff (Karr and Schlosser 1978).

Wetlands and riparian floodplains also affect lotic environments; however, their degree of influence is complex and largely determined by the extent, timing, frequency, and duration of water exchange between these ecosystems and the adjacent stream or river (Kibby 1978). Overbank flow is a natural process which builds floodplain features such as natural levees and supplies water to adjacent lowlands which serve as a storage site for excess runoff (Nunnally and Keller 1979). During flood events water velocities are greatly reduced in floodplains and wetlands relative to the main river channel. As a result, there can be considerable deposition of sediment and attached chemicals and nutrients in these areas. Alluvial floodplains act as sinks for a number of potential contaminants, including pesticides, nitrogen, phosphorus, and sewage (Kuenzler et al. 1977, Wharton and Brinson 1978, Karr 1980). They also serve as a temporary storage and processing area for organic matter and debris (Merritt and Lawson 1978). During flooding, accumulated organic material is washed back into streams so that rivers with riverine wetlands tend to carry more organic matter than those without wetlands (Kuenzler et al. 1977, Brown et al. 1978).

STREAM HABITAT MODIFICATIONS

An understanding of the complex relationships and interactions involved in the development and maintenance of stream habitat structure and dynamics is necessary to fully comprehend the impact of continuing watershed modifications by man. By disrupting stream equilibrium, land-use modifications and/or direct alterations of channels commonly result in marked changes in the structure and stability of stream habitats. These effects are further compounded by interrelationships among stream habitat components.

Negative impacts of changing land-use primarily involve modifications of watershed hydrology and are perhaps most severe in small stream environments. Clearing of vegetative cover, for example, reduces soil infiltration rates, and thereby leads to increased runoff, higher peak flows, and more frequent flooding (Hornbeck et al. 1970). Changes in channel width, depth, sinuosity and meander wavelength are generally required to compensate for these hydrologic changes. Hence, a long period of marked channel instability with considerable bank erosion and lateral shifting occurs before equilibrium is restored (Schumm 1971). Since higher spring runoff leads to decreased soil moisture storage, the extent and severity of summer and fall low flow periods is also enhanced. In some streams (e.g., where sediment loads are low), increased discharge associated with higher runoff results in channel downgrading and lowering of the water table (Behnke and Raleigh 1978).

Effects of land-use changes are compounded by removal of nearstream vegetation. Elimination of nearstream vegetation destabilizes streambanks, and together with higher discharge, leads to increased channel erosion (Patric 1975, Nunnally 1978). In the absence of a vegetated, nearstream buffer strip, increased runoff results in large losses of sediment (Karr and Schlosser 1978) and nutrients (Likens et al. 1970) from the terrestrial to aquatic component of watersheds. Nutrient enrichment, coupled with increased solar input and higher water temperatures (caused by a lack of nearstream canopy)(Brown and Krygier 1970), commonly results in choking algal blooms (Likens et al. 1970) that drastically alter stream habitat characteristics during low flow periods in summer and fall (Karr and Dudley 1981).

In addition to vegetative removal associated with extensive land-use changes (including grazing), nearstream vegetation is commonly cleared to facilitate small stream channel modifications in drainage, flood control, and bank stabilization projects. Of the various methods employed to achieve these purposes, extensive widening, deepening, and/or straightening of stream channels have the most severe environmental impacts. The immediate effect of these channelization activities is destruction of the equilibrium that had evolved in the watershed (Nunnally 1978). Channel dredging, for example, effectively lowers the local base level of tributaries and thereby initiates a cycle of erosion in those streams (Nunnally and Keller 1979). Straightening a channel has the hydraulic effect of increasing the slope, which the stream accomodates by increasing channel width through bank erosion. Attainment of a new equilibrium requires a wider and shallower channel and results in a permanent loss of habitat complexity (i.e., pool-riffle development). Straightened streams have remained straighter, wider, and shallower than natural, meandering streams for 60 to 80 years following channelization (Elser 1968, Zimmer and Bachmann 1976). When channel widening is prevented by bank stabilization measures, the straightened stream adjusts by bed scour. This either leads to bed armoring or uniform channels with unstable substrates.

Effects of straightening, deepening, or widening vary with, as well as modify, discharge regimes. Since the resulting uniform channel satisfies only one set of discharges, altered streams tend to undergo bank erosion during high flows and deposition during low flows. During runoff events, the magnitude of peak discharge is greatly increased in altered streams (Campbell et al. 1972) since larger quantities of water are shunted at a faster rate from the land surface into and through the straightened channel. Higher peak flows and associated sediment loads may also increase the flood hazard in downstream reaches (Henegar and Harmon 1971). Low flows are also accentuated in modified watersheds due to altered channel morphology and/or reduced groundwater storage during runoff events (Wyrick 1968). Channelized sections of streams commonly dry up completely during summer droughts while unchannelized areas retain discontinuous pools (Gorman and Karr 1978, Griswold et al. 1978).

In large rivers, channel straightening and dredging are conducted for both flood control and navigation purposes, and have the same effects on physical characteristics of these environments as in small streams. These include (1) increased turbidity and siltation, (2) creation of an unstable environment characterized by shifting sand substrates, wide water-level and associated physico-chemical fluctuations, and considerable bank erosion, and (3) a permanent reduction in habitat structure and complexity (Congdon 1971). Channel straightening has also resulted in a tremendous reduction in river lengths (over 50% in some drainages)(Congdon 1971, Funk and Robinson 1974).

The physical integrity of large rivers is also significantly altered by bank stabilization and navigation structures (i.e., levees, dikes, locks, and dams). Hydraulic characteristics of main river channels are particularly affected as levees and dikes constrict flow while locks and dams create a lacustrine environment. Moreover, by restricting flow to main river channels, levees, dikes, and wing dams have resulted in a significant loss of extra-channel habitats (Ellis et al. 1979, Vanderford 1980) and severing of the protective coupling with wetlands and floodplains.

The physical environment of large streams and rivers is also altered by modifications affecting tributary streams. Increased flooding (Henegar and Harmon 1971) and siltation (Vanderford 1980), for example, are primarily due to higher inputs of sediment and runoff from modified watersheds upstream.

SUMMARY

As this section clearly demonstrates, attributes of stream channels are determined by complex hydrologic processes originating on the land and proceeding from headwaters to downstream reaches. Modifications of these processes and dynamics on the land, at the land-water interface, or within stream channels profoundly affects physical habitat structure in running water ecosystems.

SECTION 4

BIOLOGICAL FOUNDATIONS OF HABITAT PROTECTION

Characteristics of biotic communities in warmwater streams are determined by interactions of a multitude of factors internal and external to the stream (Fig. 5; simplified versions given in Figs. 1 and 2). As noted in the introduction, the use of water quality attributes as surrogates for measurement of biotic integrity is a long established approach. In this report we demonstrate the importance of other determinants (especially physical habitat characteristics) of biotic integrity. This section provides a brief review of literature on this subject, including many detailed examples. First, we outline general distributional patterns along headwater to large river gradients. Second, we describe the major habitat types that are important to stream fishes. Third, in a series of brief sections we discuss the importance of cover, substrate, and fluvial characteristics to fishes. Finally, we review impacts of modifications to the physical environment of stream ecosystems in relation to their effects on biotic integrity.

GENERAL DISTRIBUTION OF FISHES IN STREAMS AND RIVERS

Since the pioneering work of Shelford (1911), numerous studies have demonstrated that fish communities vary along the continuum from headwater streams to large rivers (Burton and Odum 1945, Huet 1959, Kuehne 1962, Minckley 1963, Sheldon 1968, Harrel et al. 1967, Whiteside and McNatt 1972, Tramer and Rogers 1973, Gorman and Karr 1978, Horowitz 1978, Evans and Noble 1979, Platts 1979, Baker and Ross 1981, Schlosser 1981a,b). Although some species exhibit longitudinal zonation patterns suggesting adaptation to habitat conditions correlated with stream size, others are broadly distributed and can be found in small streams to large rivers.

Distributions of stream fishes may also vary over time and/or with changing environmental conditions. For example, in spring, many warmwater fishes migrate from rivers into headwater streams to spawn (Larimore et al. 1959, Hall 1972, Hubbs et al. 1977, Karr and Dudley 1978, Toth et al. 1981). Their young may remain in these small streams for a year or more before moving downstream to a receiving river where they spend most of their adult life. Other species migrate into tributary streams during fall and spring but reproduce in downstream rivers in summer (Mendelson 1975, Toth et al. 1981). Some lotic fish populations may actually be composed of both sedentary and mobile groups depending upon the relative suitability of local habitats, particularly during changing environmental conditions (Funk 1957, Fagen 1962, Harima and Mundy 1974, Karr and Dudley 1981). Species requiring specific habitat conditions may undergo extensive movements to maintain that association in unstable or fluctuating environments. Populations may be highly sedentary when their habitats are relatively stable or the species is adapted to a wide range of conditions.

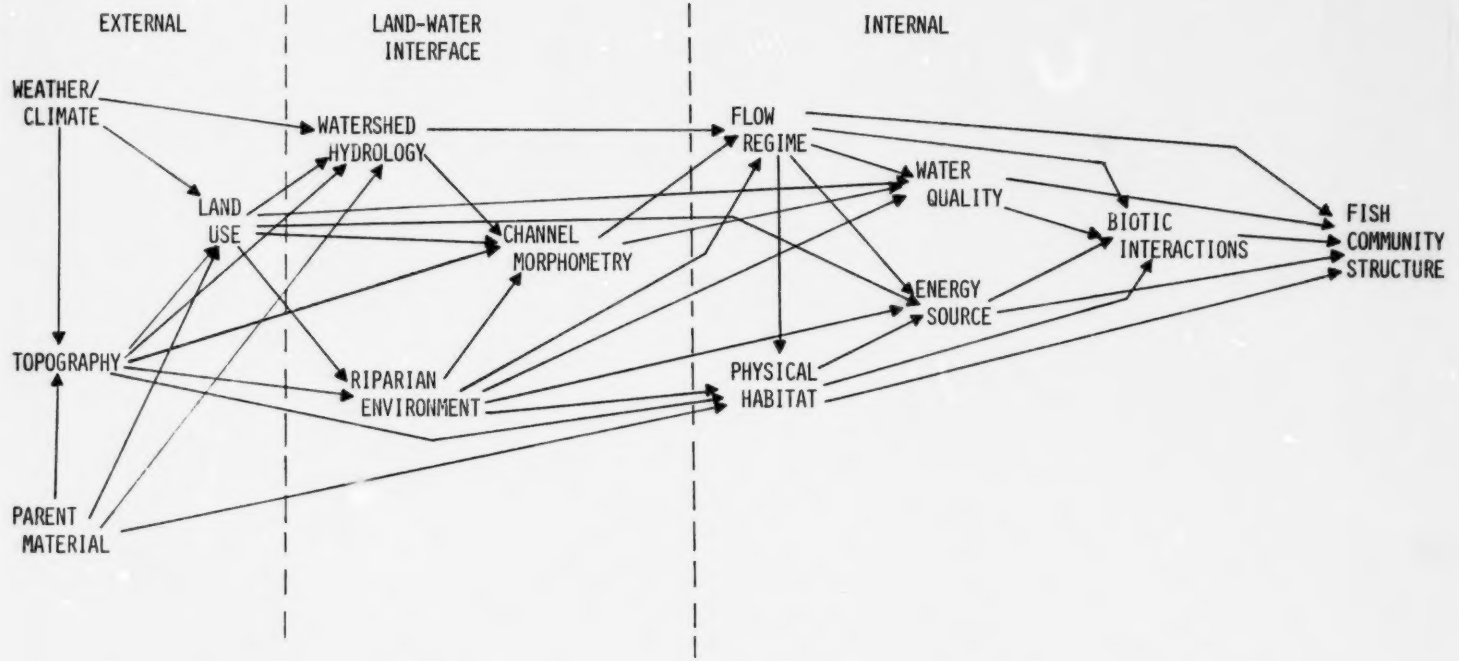
EXTERNAL
LAND-WATER INTERFACE
INTERNAL
WEATHER/ CLIMATE
TOPOGRAPHY
PARENT MATERIAL
LAND USE
WATERSHED HYDROLOGY
CHANNEL MORPHOMETRY
RIPARIAN ENVIRONMENT
FLOW REGIME
PHYSICAL HABITAT
WATER QUALITY
ENERGY SOURCE
BIOTIC INTERACTIONS
FISH COMMUNITY STRUCTURE

Figure 5. Detailed conceptual model of the interaction of terrestrial environment, land-water interface and in-stream factors that govern the characteristics of fish communities of warmwater streams.

These distribution patterns clearly indicate that management of lotic fish populations may transcend boundaries of stream reaches. Hence, preservation of fish community integrity requires an integrative view of the entire stream network.

FISH HABITAT TYPES

Fish species in streams and rivers are associated to various degrees with distinct habitat types. These habitats form primarily as a result of natural fluvial processes (see Section 3), and their characteristic physical and chemical attributes vary considerably with discharge. Like their general distribution patterns, the habitat in which a stream fish species is found may change with age, sex, reproductive state, geographic area, and/or fluctuating environmental conditions.

Pools, riffles, and raceways are the primary habitat divisions for fishes in small to medium-sized streams (Fig. 6; see also Trautman 1957, Pflieger 1975, Smith 1979, Schlosser 1981a). Riffles are areas of relatively swift current velocity and shallow depth while pools characteristically have deep water and slow current. Raceways have intermediate, and typically more uniform depth and rate of flow. Although stream fishes tend to be ecologically and morphologically specialized for exploiting a particular habitat type (Gatz 1979), some degree of plasticity is common.

In addition to these main channel habitats, large river environments have a diverse array of other habitat types (Fig. 7) that are of critical importance to riverine fishes. Side-channel and extra-channel habitats, for example, provide feeding, spawning, nursery, and overwintering areas for many riverine fish species (Table 8; Schramm and Lewis 1974, Funk and Robinson 1974, Vanderford 1980). Due to the dynamic nature of river ecosystems, side- and extra-channel habitats are continually created and destroyed by fluvial processes. However, under natural equilibrium conditions, a mosaic of these habitats, including side-channels, sloughs, and backwater lakes and ponds is maintained in association with the main channel. The diversity of environmental conditions along the transition from side-channels to backwater lakes is reflected by the different fish species that utilize these habitats (Table 9).

Side channels are departures from the main channel and main channel border, through which there is current during normal river stage. They may range from fast-flowing, sandy bottom channels to sluggish, silt bottom streams that wind through marshy areas. Many commercial species utilize side channels throughout the year, while others use these areas as rearing and overwintering habitat.

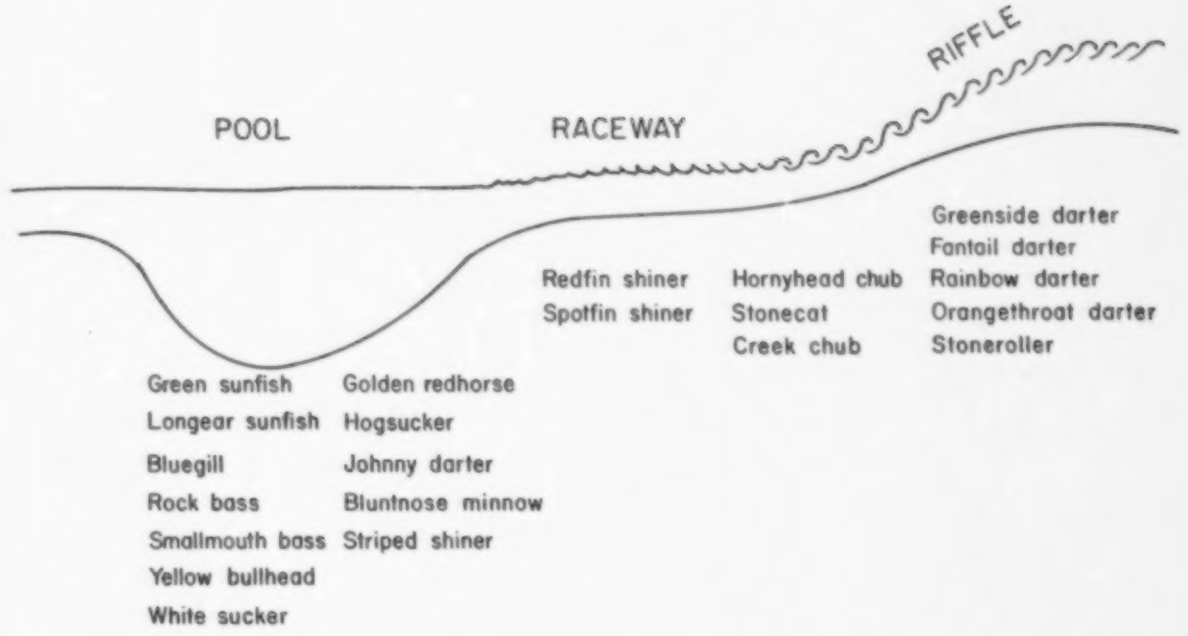
RIFFLE
POOL
RACEWAY
Greenside darter
Fantail darter
Rainbow darter
Orangethroat darter
Stoneroller
Redfin shiner
Spotfin shiner
Hornyhead chub
Stonecat
Creek chub
Green sunfish
Longear sunfish
Bluegill
Rock bass
Smallmouth bass
Yellow bullhead
White sucker
Golden redhorse
Hogsucker
Johnny darter
Bluntnose minnow
Striped shiner

Figure 6. Fish-habitat associations in a small Illinois stream. Note that some species are typically found in transition zones between major habitat divisions (Adapted from Schlosser 1981)

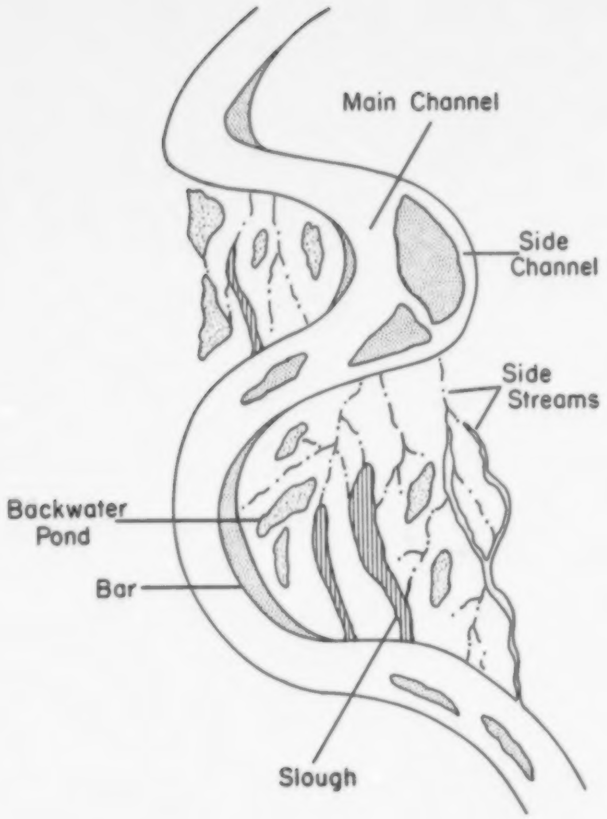
Main Channel
Side Channel
Side Streams
Backwater Pond
Bar
Slough

Figure 7. Diagrammatic representation of major habitats associated with large river environments.

TABLE 8. LARGER FISHES FROM THE UPPER MISSISSIPPI RIVER THAT USE SIDE-CHANNELS OR EXTRA-CHANNEL HABITATS (i.e., SLOUGHS, SIDE STREAMS, AND BACKWATER LAKES AND PONDS) AS SPAWNING, REARING, AND /OR WINTERING AREAS (From Vanderford 1980).

Species
Walleye
Sauger
Northern pike
Largemouth bass
Smallmouth bass
White bass
Rock bass
Crappie
Bluegill
Yellow perch
Channel catfish
Bullhead
Freshwater drum
Sturgeon
Paddlefish
Bowfin
Carp
Redhorse
Largemouth buffalo
Smallmouth buffalo
Goldeye
Gizzard shad
Gar
American eel

Sloughs and side streams include relatively narrow branches or offshoots of other bodies of water, and characteristically have mud bottoms, abundant submerged and emergent aquatic vegetation, and little or no current at normal water stage. Many sloughs and side streams are former side channels that have been cut off by sedimentation. Although a few species are found in this habitat throughout the year, others depend on sloughs and side streams primarily for spawning and nursery areas.

Backwater lakes and ponds have little or no flow, relatively shallow depths, and a thick bottom layer of silt, sand, and decaying organic matter. A diverse array of fishes, including commercial and sport species, utilize these areas. Deeper regions provide overwintering areas and emergent beds of aquatic vegetation are used as spawning habitat during high, spring flows.

Other riverine habitats, such as sandbars, shoals, mudflats, and seasonally flooded bottomland hardwood forests, meadows, and prairies are also utilized on a limited basis as spawning, rearing and feeding areas for selected species.

To maintain fish diversity and productivity in lotic ecosystems all main channel and extra-channel habitats must be preserved.

TABLE 9. DIFFERENCES IN FISH COMMUNITY STRUCTURE ACCOMPANYING SUCCESSIONAL CHANGES IN SIDE-CHANNEL HABITATS ALONG THE UPPER MISSISSIPPI RIVER. PERCENTAGES ARE BASED UPON THE TOTAL NUMBER OF FISH CAUGHT (ELECTROFISHING) IN EACH SIDE-CHANNEL (FROM ELLIS ET AL. 1979)

	Side Channel		
	Buzzard	Orton-Fabius	Cottonwood
Flow Conditions	Riverine	Riverine at high river stage, little flow-through during normal or low river stages	Lake-like, No flow-through at normal or low river stages
Dominant Species	Carp (30%) Gizzard shad (25.8%) Emerald shiner (12%)	Carp (37.2%) Gizzard shad (17.1%) Bluegill (7.8%)	Gizzard shad (30.7%) Bluegill (17.7%) Carp (15.0%) White crappie (11.5%)
Unique Species[1]	Skipjack herring, Black bullhead, Blue catfish	River shiner, Stonecat	Bowfin, Highfin carpsucker, Warmouth
Species Group			
Game fish[2]	2.6%	2.8%	5.1%
Panfish[3]	9.5	19.7	33.3
Catfish	2.6	3.5	1.4
Predatory Rough fish[4]	3.2	3.7	2.6
Forage fish[5]	39.4	24.3	36.0
Rough fish	42.6	46.1	21.6

1. Only captured in indicated side-channel
2. Northern pike, Largemouth bass, Smallmouth bass, Walleye, Sauger
3. White bass and all centrarchids other than black basses
4. Shortnose gar, Longnose gar, Bowfin
5. All minnow species, Gizzard shad, Shipjack herring

PHYSICAL HABITAT CHARACTERISTICS

Preferences exhibited by fish species for specific habitat types, as well as their overall distribution in river systems, reflect the suitability of a complex of physical, chemical, and biological factors. That is, fish species assess a particular habitat or reach of stream in a multivariate way. Physical characteristics of lotic environments are of major significance in these assessments. Biotic variation along headwater to mouth gradients, for example, coincide with changes in the diversity of physical habitat parameters (Gorman and Karr 1978, Horowitz 1978, Platts 1979, Vannote et al. 1980, Schlosser 1981a). Similarily, decreased habitat diversity may account for some of the decline in fish species diversity from the eastern to western region of the central plains (Cross 1970). Segments of these stream systems which extend into the Rocky Mountains retain diversified habitat as well as some species of fishes that were prevalent on the eastern fringe of the prairie region but absent from intervening areas.

Although fish species diversity is generally best correlated with multidimensional habitat diversity (Gorman and Karr 1978), individual physical parameters may, at times or for some species, assume overriding importance. Recognizing that the influence of physical factors on a fish species or community may vary with the chemical regime, time of the year, and/or complement of species present (e.g., through competition or predation effects), the following relationships between physical parameters and lotic fishes are critical components of ecological integrity in stream and river ecosystems.

Cover

Cover in lotic environments may be divided into two rather ill-defined classes: instream and nearstream cover. Instream cover includes undercut banks, tree roots, large rocks, logs, brush, and aquatic vascular plants, while nearstream cover refers to an array of factors such as vegetation type, angular cover density, and other characteristics of the riparian environment.

A common attribute of instream cover features is that they tend to attract and concentrate fish. Functionally, they are important to fish because they provide spawning sites, protection from current or predators, or hiding places from which predators ambush prey; or because they support important food resources or lead to changes in stream morphology that increase habitat diversity (Marzolf 1978, see also Section 3).

The importance of cover has been most intensively investigated in coldwater streams where, for example, the relative amount of various forms of cover may largely account for spatial variation in brook trout density (Hunt 1971) and steelhead and cutthroat trout standing crop (Nickelson and Hafele 1978). In warmwater streams, instream cover has similar, but perhaps, broader impacts on fish communities. In the

Missouri River, the standing crop of all fish was 25% higher, and that of catchable-size fish 51% higher, in a section with snags relative to a comparable section without instream cover (Hickman 1975). Some striking differences in community structure were also observed (Table 10). In a small Illinois stream, fish biomass was 4.8 to 9.4 times higher in a section with instream cover relative to an adjacent section that was cleared of all cover features (P. L. Angermeier, Univ. of Illinois, unpublished, Karr and Dudley 1981). Fish species diversity may also be higher in sections of streams with instream cover (Sheldon 1968).

Instream cover is particularly important to many piscivores since these features provide hiding places from which they ambush their prey. Large creek chubs, for example, tend to concentrate in pools with undercut banks and/or large rocks or submerged logs (Fraser and Sise 1980), and the presence of smallmouth bass in small streams appears to be restricted to areas with large cover structures (Paragamian 1980). Similarily, walleye and its European counterpart, the pikeperch, are restricted to river habitats with low light levels (a function of depth, overhead cover, and turbidity)(Kitchell et al. 1977). Helfman (1979, 1981) argued that fish in shaded habitats are able to see fish in sunlit surroundings better, and at greater distances, than vice versa. However, he found that small fish species are as likely to be found in shaded areas as larger predators, suggesting that such areas may also afford prey species protection from predation.

TABLE 10. STANDING CROP OF DOMINANT FISHES IN SNAG AND SNAGLESS SECTIONS OF THE MIDDLE FABIUS RIVER, MISSOURI (Adapted from Hickman 1975)

	% of total standing crop	
Species	Snag	Snagless
Carp	24.3	20.4
River carpsucker	23.6	20.3
Channel catfish	17.9	12.7
Redhorse[1]	12.2	26.7
Green sunfish	7.6	8.7
Smallmouth bass	3.4	1.6
Bullhead[2]	3.4	1.3
Freshwater drum	1.5	3.8

1. Includes Shorthead and Golden redhorse

2. Includes Yellow and Black bullhead

Instream cover also provides refuge from the rigors of the environment. Many fish that occupy regions with swift current spend a large proportion of their time behind large rocks or boulders (Cummins 1972). In fact some benthic riffle species occur within the interstices of loosely consolidated gravel and cobbles (Hynes 1970, Stegman and Minckley 1959, Toth 1978). Permanent and stable cover structures offer similar refuge for pool and raceway inhabiting fishes during elevated flows. By providing shade, instream structures also moderate water temperatures (Hickman 1975).

Aquatic macrophyte beds perhaps best illustrate the diverse roles of instream cover. For example, although piscivores commonly lurk in aquatic vegetation, the interior of dense beds provides refuge for small prey species. Aquatic plants also serve as spawning and feeding areas for a number of stream fishes. In fact, the degree of association with aquatic vegetation forms the basis of resource partitioning in some stream communities (Baker and Ross 1981, S.T. Ross, University of Southern Mississippi, pers. communication). Beds of aquatic plants also increase habitat diversity by constricting flows and leading to increased scouring, deepening of pools, and undercutting of banks (Hunt 1979).

In streams and rivers with unstable substrates, instream cover structures are particularly important to fish because they lead to increased habitat diversity (e.g., by scouring pools, see Section 3) and provide substrate for as much as 90% of the macroinvertebrate biomass (Marzolf 1978, Wharton and Brinson 1978). Wood debris also provides critical substrate for invertebrate populations in high gradient, bedrock streams (Triska and Cromack 1979).

One of the most important functions of instream cover in headwater streams is its role in trapping terrestrial litter. Inputs of terrestrial organic matter are a primary energy source for the biota of lotic environments (Fisher and Likens 1973, Cummins 1974). Efficient utilization of this organic matter is dependent upon its retention in headwater areas in the form of leaf packs and debris dams (Reice 1974, Bilby and Likens 1980). Leaf packs form on the upstream sides of large rocks, tree branches, or other obstructions. Debris dams trap larger accumulations of litter and form when a piece of large woody material, such as a tree branch, becomes lodged in the stream channel. These accumulations of leaf litter and other coarse terrestrial debris are colonized by "shredding" invertebrates and thereby converted to fine particulate organic matter. Some of the fine particulate organic matter is deposited behind debris dams while the rest is transported downstream. In either case it serves as the principle source of energy for another group of invertebrate consumers (collectors). In intermediate sized rivers, autochthonous organic production by algae and aquatic macrophytes may provide an additional source of energy for aquatic food webs, and other invertebrate functional groups (scrapers and grazers) become dominant. In large rivers, high turbidity tends to limit autochthonous production and fine particulate organic matter inputs from upstream again forms the base of the food chain.

Since aquatic invertebrates are a primary food source of many lotic fishes (Trautman 1957, Pflieger 1975, Smith 1979), the role that inputs of terrestrial litter and debris plays in trophic-energetic relationships in streams and rivers constitutes one of the most important ways that nearstream cover affects fish communities. Nearstream vegetation also supports terrestrial insect prey (Meehan et al. 1977) and is clearly the source of most instream cover, including undercut banks (which are stabilized by vegetative root systems). Moreover, nearstream vegetation that extends over and close to the water surface (e.g., tree limbs and branches) provides overhead cover much like instream structures.

Another particularly important function of nearstream vegetation in headwater reaches is the stability that it lends to these small stream ecosystems. By stabilizing streambanks, intercepting eroding sediment from the adjacent land surface, moderating water temperatures, and limiting growths of choking algal blooms and aquatic macrophytes (see Section 3), nearstream vegetation is largely responsible for maintaining the physical integrity of small stream channels over a wide range of environmental conditions. This stability in the physical environment is reflected by its biological components, particularly the fish fauna. The importance of nearstream vegetation is best illustrated in modified streams where forested reaches provide critical refuges for fishes during severe environmental conditions (Karr and Gorman 1975). Fish communities in forested regions of modified streams also contain permanent residents and tend to be more stable throughout the year than areas with little or no woody riparian vegetation.

Although the importance of in- and nearstream cover to biotic integrity is clear, potential conflicts with other stream uses (e.g., flood control or drainage) necessitates establishment of priorities regarding the type and amount of cover to be maintained. Foremost consideration must be given to preservation of nearstream vegetation, particularly in headwater reaches but also in larger streams and rivers, because its contribution to ecosystem structure and function is critical to ecological integrity. Extensive instream cover is required in streams, including spawning and rearing areas, where viable sport and commercial fish populations are desired. Instream cover is also needed to provide habitat diversity in streams and rivers with unstable substrates or high gradients. In all other streams and rivers, variable amounts (depending upon conflicts with other stream uses) of instream cover should be preserved to enhance fish species diversity and productivity.

Substrate

Various types of substrate and their degree of sorting along and across stream channels influence characteristics of lotic fish communities in a number of ways. For example, in headwater streams, effects of drought on fish communities are moderated by the water retaining capacity of impervious bedrock and clay substrates (Larimore et al. 1959, Evans and Noble 1979). However, sorting of alluvial substrate particles is of broader significance in warmwater streams, where fish species diversity increases with an increase in substrate diversity (Gorman and Karr 1978). Individual fish species, as well as different sex and age classes of the same species (Winn 1958), tend to be found in association with a specific size-range of substrate particles (Trautman 1957, Pflieger 1975, Smith 1979). The proportion of gravel and cobble substrates, for example, is an excellent predictor of smallmouth bass abundance in small rivers (Fig. 8; Paragamian 1980, 1981).

The actual value of a particular substrate type or size to a given fish species may be related to cover, spawning, or feeding. As indicated above, some fish species find shelter from the current and/or predators behind rocks or within crevices in the substrate (Cummins 1972, Toth 1978). Successful spawning by many species is dependent upon appropriate substrate for egg deposition and development. Among salmonids, survivorship during embryo to alevin emergence stages is directly related to the geometric mean diameter of the spawning substrate (Shirazi and Seim 1979). Such detailed relationships have not been described for warmwater fishes, but rigid preferences for either rock, gravel, or sand substrates segregate a number of species (Trautman 1957, Pflieger 1975, Smith 1979) and determine their distribution and relative abundance in streams with different physiographies.

In addition to the importance of substrate as cover, fish associations with particular substrate types during the non-breeding season are largely a result of feeding relationships. These involve morphological adaptations of fish as well as the distribution of their invertebrate prey. Mouths of benthic fishes, for example, are adapted for exploiting food resources associated with different substrates. Hence, many suckers feed in soft (e.g., silt covered) bottoms while stonerollers scrape the surfaces of rocks. Morphological characteristics that are seemingly unrelated to feeding may also be involved. Slight differences in body flexibility and scale size, for example, correlates with the fantail darter´s ability to exploit prey within smaller substrates than the rainbow darter (Toth 1978).

The distribution and relative abundance of invertebrates among different substrate types also plays a major role in fish-substrate associations, including those involving fish species that depend upon benthic invertebrates for food but do not directly feed off the bottom. Significant differences in invertebrate community structure and production are found within different substrates (Tarzwell 1937, Hynes 1970) and are largely due to the diversity, sorting, and physical stability of particle sizes.

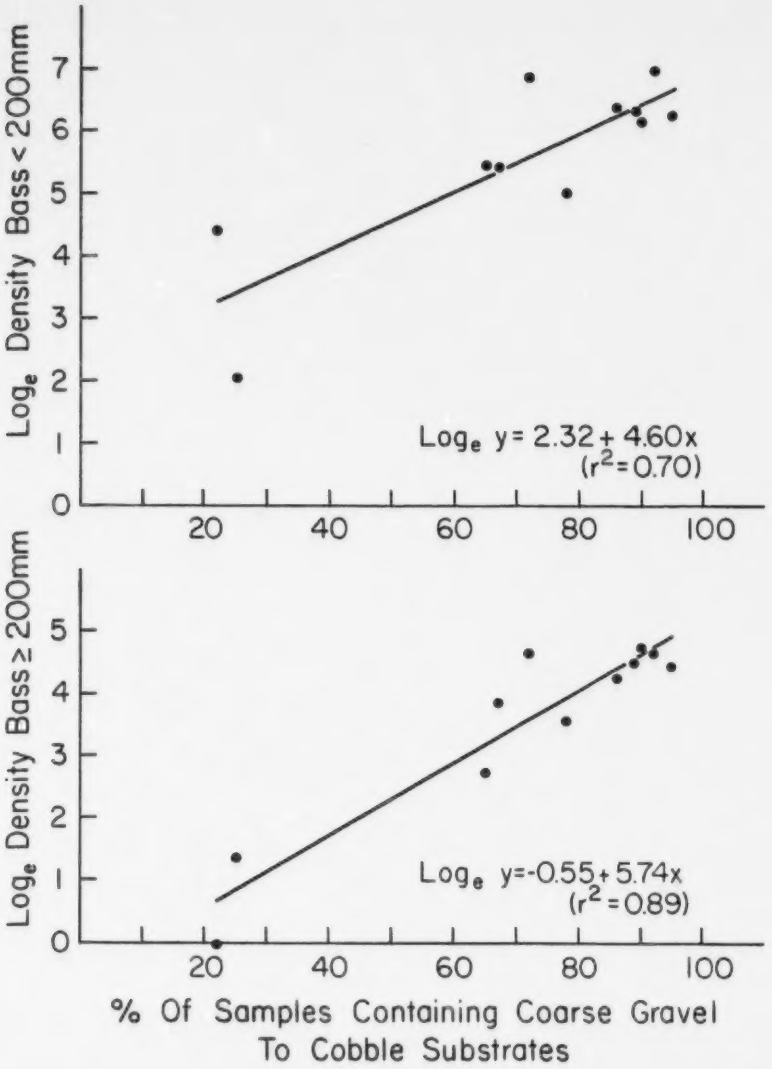

Figure 8. Relationships between smallmouth bass density and amount of coarse gravel to cobble substrates found in sections of the Maquoketa River, Iowa, 1978 (Adapted from Paragamian 1981)

Changes in substrate characteristics due to seasonally varying flow conditions lead to associated changes in invertebrate community structure (deMarch 1976). During spring, high current velocities result in well-sorted particle sizes and the number of invertebrate species associated with each substrate type is highly correlated with habitat heterogeneity (i.e., particle size distribution). As current velocities decrease during summer months, silt and sand are deposited in the interstices of coarser substrates. Habitat heterogeneity is gradually reduced and invertebrate species richness is more correlated with sorting of substrates than mean particle size.

The kinds of invertebrates associated with each substrate type are influenced by physical characteristics of the habitat (deMarch 1976). Since sand is highly unstable, only invertebrates with similar hydrological properties are consistently found in this habitat. Silt is fairly stable at a range of low current velocities but the density and diversity of organisms that can live in silt substrates is severely limited by a lack of interstitial spaces.

Boulder substrates possess unique temporal stability and in contrast to other substrate types have a greater affect on water flows than vice versa. Moreover, in winter, turbulence produced within boulder habitats keeps them open while other habitats freeze solid. Hence, invertebrate species diversity in boulder habitats is consistently high and includes long-lived species as well as ephemeral types that are found associated with other substrates.

Habitats with substrates finer than boulders but coarser than sand are fairly stable over varying flow conditions but are subject to silt and sand encroachment during depositional periods. Seasonal succession of species is typical of the invertebrate fauna associated with these substrates (Grant and Mackay 1969).

The contribution of substrate diversity to ecological integrity in streams and rivers must be preserved. Natural substrate diversity and sorting can only be maintained by preventing excessive sedimentation. This requires effective measures to check sediment inputs. A Federal Water Pollution Control Administration (1968) advisory committee on water quality indicated that waters normally containing 80 to 400 mg/l suspended solids are unlikely to support good freshwater fisheries. Integral components of fluvial processes, including natural stream morphology and flow characteristics, must also be maintained, since these parameters are responsible for particle-size sorting and cleansing of substrates.

Fluvial Characteristics

A number of highly correlated habitat attributes, including stream size and gradient, current velocity, depth, and discharge are discussed under this heading. Spatial and temporal variability in these parameters exerts a major influence on the structure of stream fish communities. Available habitat space, for example, is linked to stream size and is partially responsible for faunal changes along headwater to mouth gradients (Shelford 1911, Burton and Odum 1945, Kuehne 1962, Harrel et al. 1967, Sheldon 1968, Evans and Noble 1979, Baker and Ross 1981, Schlosser 1981a). Many species of centrarchids and catostomids require fairly large pools and do not appear in streams until they are large enough to provide these conditions (Burton and Odum 1945, Kuehne 1962, Paragamian 1980). Sheldon (1968) found that faunal changes over a pool-riffle spectrum duplicated those from the headwaters to downstream areas, with depth accounting for 66% of the variance in species diversity. Evans and Noble (1979) also found species diversity to be highly correlated with depth, but indicated that species richness was influenced by interactions among a number of environmental correlates along the longitudinal gradient. Pool area may account for over 50% of the variation in brook trout density (Hunt 1971), and pool volume explained about 94% of the variation in standing crop of juvenile coho salmon (Nickelson and Hafele 1978). In the latter study, depth and current velocity were also significant factors in models relating habitat quality to variations in standing crop of steelhead and cutthroat trout. High water velocities may reduce the effective depth of pools because fish are not able to occupy the entire water column (Sheldon 1968).

Gorman and Karr (1978) demonstrated that fish species diversity in headwater streams increases with both current and depth diversity. This indicates that different species occupy habitats with different depths or current velocities. Major changes in these parameters tend to occur simultaneously in the form of pools, riffles, and raceways. Many fish species segregate along this gradient much as they do longitudinally. However, more subtle differences in depth and current velocity may also be important in spatial partitioning (Wallace 1972, Smart and Gee 1979, Matthews 1980, Schlosser 1981a), and contribute to high species diversity. For example, segregation among many stream cyprinids appears to be largely based upon their vertical position in the water column and is believed to be important in reducing competition for food (Mendelson 1975, Baker and Ross 1981). Spatial differences in depth and current velocity also segregate different sexes as well as juveniles and adults of the same species (Winn 1958, Harima and Mundy 1974, Smart and Gee 1979). Juvenile fish generally occur in riffles, shallow pools, raceways, or along stream margins, and are rarely found in deep pools. In fact, recruitment rates in small streams are dependent upon the availability of these rearing areas (Schlosser 1981a).

Gradient also influences the distribution and diversity of stream fishes. Hocutt and Stauffer (1975) found significant negative correlations between gradient and fish species richness (r=-.90) and diversity (r=-.87) in a Maryland stream. Species richness increased with a decrease in gradient from headwater to downstream stations but decreased with an abrupt increase in gradient in the lower reaches of the stream. Along European streams, fish faunal zones appear to be determined largely by gradient (Huet 1959) such that, within a given biogeographical area, rivers or stretches of rivers of like breadth, depth, and slope tend to have similar biological characteristics. However, Burton and Odum (1945) pointed out that a number of environmental factors, including temperature, oxygen concentration, current, and habitat type are correlated with slope. They found that headwater species richness was higher in low gradient streams than in steep mountain streams where headwater species appear to be physiologically adapted to a narrow range of environmental conditions. Headwater species in streams with less altitude change tend to be more generalized and, as a result, have a broader longitudinal distribution. Creek chub, for example, is a typical headwater and broad-ranging species in prairie streams; but it is not found in the headwaters of mountain streams where species such as brook trout dominate over a rather limited range of temperature conditions. Discontinuities in the longitudinal distribution of a few species, including blacknose dace, northern hog sucker, and smallmouth bass, were also linked to abrupt changes in gradient. Menzel and Fierstine (1976) compared low gradient (ca. 0.3m/km) prairie streams with moderate to high gradient (0.7 5 to 2.18m/km) woodland streams and found fish species richness and diversity to be higher in the woodland streams. In addition to having a higher gradient the woodland streams also had more developed pools and riffles, and therefore, greater depth and current diversity. Significant positive correlations occurred between gradient and fish biomass diversity (r=0.66) and gradient and number and biomass of smallmouth bass and redhorse (r=0.85 to 0.87). In contrast, the biomass of cyprinids was negatively correlated with gradient (r=-0.77). Major differences in species composition were also observed in the two types of streams (Table 11). Carpsuckers, redhorse, smallmouth bass, and fantail darter, for example, were most frequently captured in woodland streams while northern pike, johnny darter, and blackside darter were more commonly found in prairie streams. Young-of-the-year carp and white sucker were the most abundant juvenile fishes captured and showed a definite preference for prairie streams (Table 12).

Fluctuating water levels and flow regimes are characteristic of many streams and a number of studies have suggested that temporal discharge patterns regulate fish community structure. For example, fish species diversity is lower in the western plains partly because streams in this region are smaller, shallower, and more subject to intermittency than those on the eastern plains (Cross 1970). Similarly, the tendency for fish species richness to increase along headwater to mouth gradients appears to be at least partially due to a decrease in discharge variability in downstream reaches (Harrel et al. 1967, Whiteside and

TABLE 11. FREQUENCY OF OCCURRENCE OF SELECTED FISH SPECIES IN N SAMPLES FROM LOW-GRADIENT PRAIRIE STREAMS AND HIGH-GRADIENT WOODLAND STREAMS IN IOWA (From Menzel and Fierstine 1976.)

	Type of Stream	
	Prairie (N=12)	Woodland (N=36)
Northern pike	58.3	5.6
Suckermouth minnow	8.3	77.8
River carpsucker	25.0	83.3
Quillback	58.3	91.7
Highfin carpsucker	16.7	86.1
Northern Hogsucker	41.7	88.9
Bigmouth buffalo	41.7	2.8
Silver redhorse	16.7	63.9
Golden redhorse	50.0	97.2
Shorthead redhorse	66.7	100.0
Smallmouth bass	33.3	97.2
Fantail darter	0.0	52.8
Johnny darter	83.3	27.8
Blackside darter	91.7	36.1

TABLE 12. ELECTROFISHING CAPTURE RATES (NO./HR) OF YOUNG-OF-THE-YEAR CARP AND WHITE SUCKER IN PRAIRIE AND WOODLAND STREAMS IN IOWA (1974-1975) (From Menzel and Fierstine 1976.)

	July		August-September	
	Prairie	Woodland	Prairie	Woodland
Carp	31.48	0.20	3.14	1.36
White sucker	5.88	0.41	28.65	0.48

McNatt 1972, Horowitz 1978). More species are added downstream when there is a large decrease in discharge variability relative to the headwaters (Horowitz 1978). Moreover, both headwater and downstream species richness is higher in streams with relatively constant flow than in those with seasonal or highly variable runoff flow. Longitudinal replacement rates of species also appear to be lowest in the most variable sections and rivers. Species richness within feeding guilds typically increases from the headwaters to middle reaches, with piscivores consistently showing the highest addition rates. These patterns support hypotheses that predict that (1) temporally variable areas contain broad-niched species while more constant regions allow greater niche or habitat specialization (Slobodkin and Sanders 1969); (2) temporal constancy allows increased trophic complexity (Menge and Sutherland 1976) which may regulate diversity through predation; and (3) greater variability increases extermination rates which will therefore be greatest in intermittent headwaters. Kushlan (1976) observed a decline in overall fish density and a shift to dominance by large carnivores when a Florida marsh experienced three consecutive years without a dry season. Fish community structure in the marsh is apparently controlled by predation when water levels are stable; under fluctuating conditions, the number and kinds of fish are limited to those capable of repopulating the marsh following dry periods.

Temporal discharge patterns in many warmwater streams are generally characterized by high flows during the spring and early summer months, often followed by an extended period of low flow. Extended high discharge during spring may limit reproductive success of early spawning species by shortening their spawning period, decreasing food availability, washing away eggs or fry, or covering them with sediment (Starrett 1951, Winn 1958). By thinning populations, spring floods may also affect reproductive success of late spawning species since their recruits have less competition for habitat space and food resources (Starrett 1951).

Stream fishes typically find shelter during floods by moving upstream (e.g., into smaller tributaries or into more stable and protected habitats such as backwater areas; Starrett 1951, Paloumpis 1958, Fagen 1962, Hall 1972, Harrell 1978, Evans and Noble 1979). Harrell (1978) found that the six dominant fish species (based upon relative biomass) in a desert stream were the same and in the same rank order before and after a major flood. However, they all exhibited pronounced habitat shifts, suggesting that ecological plasticity is a key to their success in this flood-prone environment. Dominance by a few species may be typical of naturally stressful environments.

Fishes also respond to low discharge by shifting habitats or altering their distribution in the watershed. For example, riffle-inhabiting darter species move downstream to larger riffles as flows decrease during summer months (Winn 1958). Matthews and Hill (1980) documented changes in habitat breadth among four species of minnows in an Oklahoma river that exhibited seasonal extremes in discharge. The greatest change occurred from August to October as low water levels prevailed and all species converged to similar physico-chemical refugia. In fact, three of the species were largely confined to backwater pools. Hence, drought conditions, like floods, appear to put fish communities out of equilibrium with their habitat optima (Gorman and Karr 1978). However, for stream fish populations to persist, suitable habitats or "stream havens" (Paloumpis 1958) must be available during the most severe environmental conditions. During extended dry periods, isolated pools and/or receiving streams and rivers serve as refugia and harbor a colonization and/or breeding stock for many small stream fish populations (Paloumpis 1958, Harrel et al. 1967, Whiteside and McNatt 1972, Menzel and Fierstine 1976).

Larimore et al. (1959) investigated effects of a severe drought on fish in a small Illinois stream and found that the amount of reduction of suitable aquatic habitat varied according to local conditions along the stream's length. Water levels were lowest in silt-bottomed, low gradient reaches that flowed through intensively cultivated land, while deep pools persisted in a relatively high gradient, wooded section that flowed over an impervious clay and bedrock substrate. Mortality was not particularly high among fish trapped in isolated pools during the summer months, but increased in the fall when temperatures fluctuated drastically and decomposing leaves and plant materials increased demand for oxygen. However, the drought did not affect fish species richness since water conditions in some pools along the stream course did not reach lethal levels.

Of course, some species are able to tolerate conditions in isolated pools better than others. For example, during a summer drought in an Oklahoma river, the density of three cyprinid species increased while that of the emerald shiner decreased (Matthews and Maness 1979). Laboratory experiments suggested that the relative success of the four fish species was primarily related to their temperature tolerances, which apparently affected adult survivorship, reproductive success, and the range of microhabitats in which they could forage.

The source of flow, particularly in small headwater streams, to a large extent determines the magnitude of temporal changes in discharge, as well as variation in correlated habitat parameters such as depth, current velocity, turbidity, and water temperatures (Horowitz 1978). Temperature preferences of orangethroat and orangebelly darters correspond well with the occurrence of the former in thermally stable spring runs and the latter in shallow rivers subject to wide temperature fluctuations (Hill and Matthews 1980). Trout streams in Wisconsin appear to be dependent on groundwater inflows for maintaining suitable temperatures, spawning habitat, shelter (e.g., adequate depth plus an abundance of submerged hiding places), living space, and supply of nutrients (White and Brynildson 1967).

Since diversity in depth and current velocity are critical to lotic fish community integrity, they must be preserved by maintaining natural habitat heterogeneity in the form of pools, riffles, and raceways. Much of the potential fish species diversity of streams, including the presence of top predators and sport fishes, will be insured by the presence of deep pools. Moreover, survival of stream fish populations during naturally occurring low flow periods is dependent upon persistence of deep, pool habitats as refuges. However, species specifically adapted for faster flowing and shallower habitats are also integral components of stream fish communities. Hence, riffles and raceways are required to maintain these species populations. These habitats are also prime rearing areas for juveniles of many pool species (Schlosser 1981a).

Although seasonal variation in discharge is common in warmwater stream ecosystems, prolonged low or high flow periods are prevented by buffering characteristics of natural watersheds. In view of the effects of severe floods and droughts on fish communities, key hydrologic components must be preserved, in at least some regions of watersheds, to maintain as stable flows as possible.

HABITAT MODIFICATIONS

Effects of modifications of watershed hydrology and channel structure on biotic integrity provide further evidence of the importance of physical habitat parameters in lotic ecosystems. Much of the loss of biotic integrity in streams and rivers is attributable to man-caused degradation of these physical habitat attributes.

Small Stream Environments

As suggested by previously described fish-habitat associations, reduced habitat complexity (i.e., pool-riffle development) typically results in a significant loss of fish species richness (North et al. 1974, King and Carlander 1976, Griswold et al. 1978). Elimination of deep pool habitats, for example, commonly results in loss of game fish populations. However, fish biomass may remain the same or even increase with a reduction in habitat diversity and/or elimination of a habitat type since densities of species that are more adapted to the altered conditions commonly increase. In modified agricultural watersheds, these compensatory changes in fish community structure typically involve shifts to dominance by species with more generalized food (i.e., omnivores) and/or habitat requirements (Karr and Dudley 1978, Schlosser 1981b). For example, when riffle habitats are eliminated by channel straightening, loss of darter biomass is generally more than compensated for by increased biomass of bluntnose minnow in the new, wide, and shallow stream channel (Toth et al. 1981).

Loss of biotic integrity in small streams is also linked to modifications of specific habitat parameters. The absence of instream brush piles, for example, may account for lower fish biomass in small stream reaches where the source of these cover structures (i.e., nearstream vegetation), as well as the environment favoring their retention, has been destroyed by channelization (King and Carlander 1976). Fish food supplies are also affected since brush piles support dense aquatic macroinvertebrate populations and removal of nearstream vegetation reduces inputs of terrestrial insects (Lynch et al. 1977).

Although direct substrate alterations (e.g., dredging) have major effects on fish populations (Bianchi and Marcoux 1975) and may be particularly devastating during spawning periods, indirect modifications of substrates have had more severe impacts on biotic integrity in the long-term. For example, a shift from sand-gravel-rubble to predominantly sand-silt substrates has led to increasing dominance by bluntnose minnow, sand shiner, and spotfin shiner in a number of Iowa stream fish communities, and also contributed to the extirpation of a fantail darter population (King 1973). In fact, siltation of substrates has been one of the major factors responsible for decreasing quality of fisheries throughout the United States (Karr and Schlosser 1978). This is due primarily to effects on reproduction, but other negative impacts of siltation, such as reduced benthic invertebrate production and elimination of cover, are also significant (see Sorensen et al. 1977 and Muncy et al. 1979 for reviews).

The combined effects of modifications of watershed hydrology and physical characteristics of stream channels lead to marked temporal instability in fish communities (Menzel and Fierstine 1976, Gorman and Karr 1978, Toth et al. 1981, Schlosser 1981b). In fact, this instability is perhaps the most symptomatic measure of degradation in small streams that have been stripped of their natural buffering capacity by the creation of uniform channels and elimination of nearstream vegetation. Associated with these conditions are drastic shifts in habitat suitability, including large fluctuations in temperature, dissolved oxygen, and water levels, choking algal blooms, and persistent erosion and siltation (Karr and Dudley 1981) that lead to frequent short- and long-range movements by fish populations. These conditions contribute to the demise of some populations (Toth et al. 1982).

Stream and watershed modifications also have a major impact on natural headwater ecosystem structure and function (Karr and Dudley 1978). As a result of frequent algal blooms and reduced inputs of terrestrial organic matter accompanying the removal of nearstream vegetation, disturbed headwater streams undergo a fundamental shift in energy flow and associated change from a heterotrophic to autotrophic community (Karr and Dudley 1978, Gelroth and Marzolf 1978). Invertebrate shredders are commonly replaced by collectors, while the fish fauna typically shifts to dominance by omnivorous taxa that are capable of exploiting rich growths of algae. During the summer and fall months, for example, modified headwater streams commonly serve as feeding areas for gizzard shad, and young carp and quillback.

Modifications of headwater ecosystems also affect biotic integrity in downstream reaches. Luey and Adelman (1980) compared the fish fauna of three streams with different degrees of upstream drainage development and found that average species diversity was significantly greater and mean biomass of fish was two times higher in downstream reaches of the least developed stream. Alterations of headwater spawning and rearing areas have led to a decline of a number of riverine fish populations, including northern pike, smallmouth bass, and walleye (Trautman and Gartman 1974). Late spawning species such as walleye are particularly affected by altered flow regimes stemming from agricultural drainage improvements since reduced flows in late spring regularly trap fry in upstream reaches that are subject to complete dewatering during summer months (H. Valiant, Manitoba Department of Natural Resources, pers.

commun.). Meanwhile, modifications of headwater streams have increased their value as feeding and nursery areas for carp, quillback, and gizzard shad and thereby contributed to increasing populations of these species in large rivers (Karr and Dudley 1978). Downstream communities may also be affected by higher organic loadings and biological oxygen demand as unprocessed litter is transported from modified headwater reaches (Marzolf 1978). Conversion of coarse organic matter to fine particulate organic matter is inefficient in uniform, unobstructed channels (Karr and Dudley 1978, Bilby and Likens 1980) and unstable sand or silt substrates (Reice 1974) created by stream and watershed modifications.

Impacts of small stream and watershed modifications indicate that several measures must be taken to preserve or restore ecological integrity in these environments. First, effective soil and water conservation practices must be implemented to maintain (1) a hydrologic balance in the watershed and (2) keep sediments and nutrients out of stream channels. Historically, the major focus of land-use programs in agricultural areas has emphasized the latter with little recognition of the significance of shifting hydrologic regimes. A vegetated, nearstream buffer strip is essential to trap eroding sediment from the land surface and to maintain stable, naturally functioning biological communities in stream channels. Extensive straightening, widening, or deepening of channels should be unequivocally prohibited to preserve stream equilibrium and habitat complexity. Short-reach channel modifications not exceeding 500 m may be permitted on a limited basis (e.g., for bridge construction and maintenance), providing adequate mitigation measures are taken to protect aquatic resources before, during, and after the alterations. In addition, to compensate for any loss of biotic integrity incurred as a result of these modifications, stream improvement measures should be implemented in other sections of the altered stream or in comparable streams in the watershed. Cumulative modifications on any single stream should not exceed 25% of the channel length. When feasible, stream restoration programs should be implemented in stream channels where past modifications have severely impaired ecological integrity. Finally, in view of their contribution to downstream biotic integrity, at least a few entire headwater streams should be preserved in their natural state in all drainage systems. Decisions regarding which streams should be partly based upon the degree of potential land and water-use impacts and within the framework of a comprehensive watershed management plan.

River Environments

Modifications of the physical environment may have an even more significant impact on fish communities in large rivers than in small streams. For example, although 30 years had elapsed since the channel was modified, the standing crop of fish in a straightened section of the Chariton River (Missouri) was 83% less than in an adjacent unmodified section (Congdon 1971). The straightened region also had eight fewer fish species. Fish samples from modified sections of the Olentangy

River, Ohio (Griswold et al. 1978) and Luxapalila River, Alabama-Mississippi (Arner et al. 1976) indicate that, in addition to consistently supporting lower fish standing crops (Table 13), straightened sections of large rivers have markedly different fish community structure than unmodified sections (Table 14). The decline in game fish populations, for example, is particularly striking. Moreover, many fish that are captured in straightened sections are actually transients that are enroute to more stable (i.e., unmodified) habitats (Table 15; Hansen 1971, Arner et al. 1976).

TABLE 13. SAMPLE BIOMASS OF FISH CAPTURED FROM NATURAL AND CHANNELIZED SECTIONS OF THE LUXAPALILA (From Arner et al. 1976) AND OLENTANGY (From Griswold et al. 1978) RIVERS.

	Average Capture Rate	
	Natural	Channelized
Luxapalila River[1]	798.7 g/net day	227.4 g/net day
Olentangy River[2]	2,028.7 g/min.	1,533.6 g/min.

1. Based upon hoop net samples (1973-1976)

2. Based upon electrofishing samples (1974-1976)

Elimination of instream cover may also have more detrimental effects on biotic integrity in large rivers than in small streams. Snag removal, for example, has contributed to a serious decline in catfish fisheries in the Missouri River (Funk and Robinson 1974). Moreover, the standing crop of all fish has been estimated to be 25% less, and that of catchable-size fish 51% less, in sections of the river without snags relative to areas with instream cover structures (Hickman 1975). Removal of snags also results in a severe reduction in fish food resources (Hansen 1971, Arner et al. 1976), since most of the aquatic invertebrate production in large, unstable-bottom rivers is associated with these structures.

Although bank stabilization and navigation structures (i.e., levees, dikes, locks and dams) have major effects on the physical environment of main river channels (particularly flow characteristics), biotic integrity appears to be more adversely affected by impacts of these modifications on extra-channel habitats. Dikes and wing dams, for example, have severely reduced the number and quality of backwater and side channel habitats on the Missouri River and thereby contributed to declines in walleye, sauger, crappie, sunfish, and black bass populations (Funk and Robinson 1974). Loss of extra-channel habitats due to installations of levees and dikes and channelization has also been linked to a decline in riverine fish species in the upper Mississippi River (Ellis et al. 1979, Vanderford 1980).

As in small stream environments and because of the severe impacts of channel straightening on ecological integrity, we recommend that these river modifications be stopped. Moreover, attempts should be made, at least in small rivers, to restore characteristics of the physical environment (particularly pool and riffle habitats) that have been destroyed by these activities. It also is clear that actions must be taken to prevent continuing degradation and loss of extra-channel habitats. This includes implementation of land conservation practices to reduce excessive sediment inputs from upstream, preventative measures to control siltation during dredging and spoil disposal operations, and employment of mitigation techniques for existing and planned navigation and bank stabilization efforts. Finally, attempts should be made to maintain instream cover structures in at least selected reaches.

SUMMARY

A number of physical attributes of stream ecosystems, including major habitat divisions as well as specific components such as cover, substrate, and fluvial characteristics, are primary determinants of biotic integrity. Man-induced modifications of these parameters alter characteristics of fish communities, often leading to their degradation. Preservation of ecological integrity in streams and rivers requires an integrative view of all factors.

TABLE 14. DOMINANT FISH SPECIES (BASED UPON THE NUMBER OF FISH CAUGHT) IN NATURAL AND CHANNELIZED SECTIONS OF THE OLENTANGY (From Griswold et al. 1978) AND LUXAPALILA (From Arner et al. 1976) RIVERS.

	Natural	Channelized
Olentangy River[1]		
Gizzard shad	0.9%	15.9%
Carp	12.1%	15.6%
Longear sunfish	18.8%	16.1%
Smallmouth bass	14.5%	4.4%
Golden redhorse	8.3%	11.7%
Rock bass	19.5%	1.3%
Green sunfish	2.8%	7.5%
Luxapalila River[2]		
	Natural	Channelized
Bluegill	16.8%	9.6%
Channel catfish	9.2%	9.1%
Blacktail redhorse	8.9%	4.8%
Largemouth bass	7.3%	3.5%
Blacktail shiner	7.3%	2.3%
Gizzard shad	3.8%	29.9%
Smallmouth buffalo	3.0%	21.5%

1. Based upon electrofishing samples (1974-1976)
2. Based upon hoop net, gill net, and electrofishing samples (1973-1976)

TABLE 15. NUMBER OF RESIDENT AND TRANSIENT FISH SPECIES CAPTURED IN NATURAL AND CHANNELIZED SECTIONS OF THE LUXAPALILA RIVER (1973-1976). A SPECIES WAS CONSIDERED TRANSIENT IF IT WAS CAPTURED IN FEWER THAN 4 OF 36 COLLECTIONS (From Arner et al. 1976.)

	Resident Species	Transient Species
Natural Section	54 (79.4%)	14 (20.6%)
Channelized Section	33 (53.2%)	29 (46.8%)

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Code letters at the end of each bibliographic entry refer to the section(s) (see Table of Contents) in which the reference was cited.

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Compares stream habitat conditions and relative populations of plankton, macroinvertebrates, fish, and mammals in old channelized, newly channelized and unchannelized segments of the Luxapalila River, Alabama-Mississippi. Significantly more fish species were captured in the unchannelized segment. Major differences in fish species composition also occerred. The newly channelized segment appeared to be dominated by transient species.

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Helfman, G. S. 1979. Fish attraction to floating objects in lakes. Pages 49-57 in D. L. Johnson and R. A. Stein (eds.) Response of Fish to Habitat Structure in Standing Water. North Central Div. Amer. Fish. Soc. Spec. Publ. No. 6. N

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Hickman, G. D. 1975. Value of instream cover to the fish populations of Middle Fabius River, Missouri. Aquatic Series No. 14. Missouri Dept. of Conservation, Jefferson City, Missouri. 7 pp. J,N,O

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Hill, L. G. and W. J. Matthews. 1980. Temperature selection by the darters, *Etheostoma spectabile* and *Etheostoma radiosum* (Pisces: Percidae). Am. Midl. Nat. 104: 412-415. N

Found that orangethroat darter exhibits active temperature selection and pointed out that this species occupies thermally stable spring runs whereas the orangebelly darter probably makes little use of temperature as a cue for habitat selection and is found in habitats with widely fluctuating temperatures.

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Found that gradient was the parameter that most influenced the distribution of species. Both number of fish species and diversity of species showed significant negative correlations with gradient.

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Horowitz, R. J. 1978. Temporal variability patterns and the distributional patterns of stream fishes. Ecol. Monogr. 48: 307-321. H,L,N

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Jahn, L. R. 1978. Values of riparian habitats to natural ecosystems. Pages 157-160 in Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. Symp. Proc., USDA, Forest Service, Washington, D. C., GTR-WO-12. D,J

Emphasizes the importance of riparian vegetation in maintaining the productivity of stream communities.

Kao, D. T. 1980. Determination of sediment filtration efficiency of grass media. In Vol. I: Sediment Filtration Efficiency of Continuous Grass Media. Univ. of Kentucky Water Resources Research Inst., Res. Report No. 124. 44 pp. H

Describes function of grass filters in retarding flow and acting as a sediment trap.

Karr, J. R. 1980. Buffer strips, resources and agricultural development in the Guanare-Masparro region of Venezuela. CIDIAT, Merida, Venezuela. 103 pp. J

Reviews functions of nearstream vegetated buffer strips and evaluates their potential value in various agricultural areas in Venezuela. Also discusses legislation pertaining to the protection of land and water resources in that country.

Karr, J. R. 1981a. An integrated approach to management of land resources. From: R. T. Dumke, G. V. Burger, and J. R. March (eds). 1981. Wildlife Management on Private Lands. Wisconsin Chapt., The Wildlife Society, Madison, Wisconsin. In press. A,B,G,L

Reviews current trends in land, water, and associated resources in intensive agricultural regions of North America. Suggests ways of improving the effectiveness of various programs concerned with the conservation of these resources.

Karr, J. R. 1981b. Assessment of biotic integrity using fish communities. Fisheries 6: 21-27. C

Proposes an ecologically based system for evaluating the biotic integrity of a stream ecosystem using fishes. A set of species composition and trophic structure metrics are the central core of the system.

Karr, J. R. and D. R. Dudley. 1978. Biological integrity of a headwater stream: Evidence of degradation, prospects for recovery. Pages 3-25 in J. Morrison (ed.), Environmental Impact of Land Use on Water Quality. Final Report on the Black Creek Project (Suppl. Comments). U. S. Environmental Protection Agency, Chicago, Illinois. EPA-905/9-77-007-D. C,G,L,O

Describes changes in the structure and functional status of stream fish and invertebrate communities resulting from stream and land-use modifications.

Karr, J. R. and D. R. Dudley. 1981. Ecological perspectives on water quality goals. Environ. Manag. 5: 55-68. A,C,D,E,G,K,L,N,O

Describes factors that determine biotic characteristics of streams. Identifies key problems demanding attention in agricultural watersheds. Discusses watershed management plans for preserving biotic integrity in agricultural areas.

Karr, J. R. and O. T. Gorman. 1975. Effects of land treatment on the aquatic environment. In Non-point Source Pollution Seminar. U. S. Environmental Protection Agency, Chicago, Illinois. Tech. Report EPA-905/9-75-007. B,I,N

Describes effects of stream habitat modifications, including channelization, removal of nearstream vegetation and sedimentation on water quality and fish community characteristics in a small agricultural watershed.

Karr, J. R. and J. J. Schlosser. 1978. Water resources and the land-water interface. Science 201: 229-34. B,D,G,J,K,O

Discusses interrelationships between nearstream vegetation, channel morphology, and water quality in natural and modified watersheds.

Keller, E. A. 1971. Areal sorting of bed load material: the hypotheses of velocity reversal. Geol. Soc. Amer. Bull. 82: 753-756. I

Keller, E. A. 1972. Development of alluvial stream channels: A five-stage model. Geol. Soc. Amer. Bull. 83: 1531-1536. I

Describes transitional stages in the progression from straight to meandering stream channels, including aspects of pool and riffle development.

Keller, E. A. 1975. Channelization: A search for a better way. Geology 3: 246-248. E

Discusses constraints imposed by channelization on stream channel stability and equilibrium. Proposes using "pilot" channels as an alternative to channelization for flood control.

Keller, E. A. 1978. Pools, riffles, and channelization. Environ. Geol. 2: 119-127. F

Demonstrated that natural channel features such as converging and diverging flows, point bars, and scour areas could be produced by manipulating slopes of channel banks.

Keller, E. A. and E. K. Hoffman. 1977. Urban streams: Sensual blight or amenity? J. Soil and Water Cons. 32: 237-240. E

Discusses channel restoration practices for urban streams.

Keller, E. A. and W. N. Melhorn. 1978. Rhythmic spacing and origin of pools and riffles. Bull. Geol. Soc. Amer. 89: 723-730. I

Keller, E. A. and F. J. Swanson. 1979. Effects of large organic material on channel form and fluvial processes. Earth Surface Processes 4: 361-380. J

Contrasts effects of large organic debris on channel structure in low gradient streams and mountain streams. In low gradient streams, debris dams led to local channel scour and widening, the formation of mid-channel bars, and backwater effects. In steep mountain streams, sediment was deposited behind channel obstructions while plunge pools developed immediately downstream.

Kern-Hansen, V. and F. H. Dawson. 1978. The standing crop of aquatic plants of lowland streams in Denmark and the inter-relationships of nutrients in plants, sediment and water. Proc. Eur. Weed Res. Council on Aquat. Weeds. J

Kibby, H. V. 1978. Effects of wetlands on water quality. Pages 289-298 in Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. Symp. Proc, USDA, Forest Service, Washington, D. C., GTR-WO-12. J

Discusses relationships between floodplain wetlands and river channels.

King, L. R. 1973. Comparison of the distribution of minnows and darters collected in 1947 and 1972 in Boone County, Iowa. Proc. Iowa Acad. Sci 80: 133-135. O

Found that despite significant habitat loss due to channelization and other activities by man, the dominant species in a number of Iowa streams have remained the same. However, water temperature and substrate alterations due to channelization and lake construction appear to have led to the extirpation of a fantail darter population.

King, L. R. and K. F. Carlander. 1976. A study of the effects of stream channelization and bank stabilization on warmwater sport fish in Iowa: Subproject No. 3. Some effects of short-reach channelization on fishes and fish food organisms in central Iowa warmwater streams. U. S. Fish and Wildlife Service FWS/OBS-76-13. O

Studied effects of "re-channelization" of short stream reaches (i.e., 0.5 km) for bridge construction. Recently channelized reaches tended to be shallower, wider, and had fewer pools and brush cover than areas above and below. The reduction in brush piles was particularly significant since they provided important substrate for invertebrates. Fish species richness was also low in modified reaches.

Kitchell, J. F., M. G. Johnson, C. K. Minns, K. H. Loftus L. Greig, and C. H. Oliver. 1977. Percid habitat: the river analogy. J. Fish. Res. Bd. Can. 34: 1936 1940. N

Klingeman, P. C. and J. B. Bradley. 1976. Willamette River Basin streambank stabilization by natural means. Oregon St. Univ. Water Resources Research Inst., Corvallis, Oregon. 238 pp. E,J

Discusses various aspects of natural means of streambank protection - physical shaping of the bank, vegetative management, and land management adjacent to the stream and its applicability in large river environments.

Kuehne, R. A. 1962. A classification of streams, illustrated by fish distribution in an eastern Kentucky creek. Ecology 43: 608-614. L,N

Describes changes in fish species richness along a stream order gradient. Suggests that the relation between a species and the range of orders it occupies reflects adaptation to local conditions.

Kuenzler, E. J., P. J. Mulholland, L. A. Ruley, and R. P. Sniffen. 1977. Water quality in North Carolina coastal plain streams and effects of channelization. Water Resources Res. Inst., Univ. of North Carolina, Raleigh, N. C., Rept. No. 127. 160 pp. J

Kushlan, J. A. 1976. Environmental stability and fish community diversity. Ecology 57: 821-825. N

Studied effects of variation in the annual wet-dry cycle on the fish community of an Everglades marsh. Found shifts in the community to dominance by large carnivores at the expense of small omnivores during years when water levels remained relatively stable. Suggests that under fluctuating conditions, the predictable cycle of water loss limits the number and kinds of fish to those capable of repopulating the marsh after dry periods. Under stabilized water conditions, large fish predators appear to exert major control over fish community structure.

Lake, J. 1978. Text of speech presented to Purdue Nonpoint Source Pollution Committee, Stewart Center, Purdue University, West Lafayette, Indiana, December 1, 1978. Published by National Association of Conservation Districts, Washington, D.C. 5 pp. G

Lane, E. W. 1937. Stable channels in erodible material. Am. Soc. Civil Eng , Trans. 63: 123-142. I

Discusses relationships between velocity distribution and bed and bank erosion and deposition.

Lane, E. W. 1955a. The importance of fluvial morphology in hydraulic engineering. Am. Soc. Civil Eng. Proc., Hydraulic Div. 81: 745-1 to 745-17. I

Lane, E. W. 1955b. Design of stable channels. Trans. ASCE 120: 1234-1279. I

Langbein. W. B. 1964. Geometry of river channels. J. Hydraul. Div. ASCE 90(Hy2): 301-312. I

Discusses energy dynamics of rivers with emphasis on how the system accomodates changes in discharge.

Langbein, W. B. and L. B. Leopold. 1966. River meanders - Theory of minimum variance. U. S. Geol. Surv. Prof. Paper 422-H. I

Discusses the energetic basis of meander formation. Provides evidence that meandering reaches are more stable than straight reaches.

Larimore, R. L., W. F. Childers, and C. Heckrotte. 1959. Destruction and re-establishment of stream fish and invertebrates affected by drought. Trans. Am. Fish. Soc. 88: 261-285. L,N

Indicated that fish populations are capable of withstanding droughts as long as water conditions in at least some regions of the stream do not reach lethal levels. After complete dewatering, 21 of the 29 fish species that had regularly occurred in the creek recolonized it within two weeks after heavy spring rains broke the drought. Lists factors determining the rate of reinvasion.

Larimore, W. R. and P. W. Smith. 1963. The Fishes of Champaign County, Illinois as affected by 60 years of stream changes. Ill. Nat. Hist. Sur. Bull. 28: 299-382. B,C

Leopold, L. B. and W. B. Langbein. 1962. The concept of entropy in landscape evolution. U.S. Geol. Surv. Prof. Pap. 500-A. I

Leopold. L. B., M. G. Wolman, and J. P. Miller. 1964. Fluvial Processes in Geomorphology. Freeman Press, San Francisco, California. 522 pp. H,I

Good general reference on hydrology and geomorphology.

Likens, G. E., F. H. Bormann, N. M. Johnson, D. W. Fisher, and R. S. Pierce 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed-ecosystem. Ecological Monographs, 40: 23-47. K

Included among the effects of deforestation were major increases in water discharge, stream channel erosion, water temperature, and export of dissolved inorganic substances. Increased nitrate concentrations were particularly significant and together with higher water temperatures and solar inputs resulted in dense algal blooms during summer months. Other effects included the elimination of debris dams and lowering of streamwater pH.

Lines. I. L., Jr., J. R. Carlson., and R. A. Corthell. 1978. Repairing flood-damaged streams in the Pacific Northwest. Pages 195-200 in Strategies for Protection and Management of Floodplain Wetlands and other Riparian Ecosystems. Symp. Proc., USDA, Forest Service, Washington, D. C., GTR-WO-12. E

Discusses streambank stabilization guidelines and practices that are presently being used in Oregon and Washington. These include: revegetation with fast-growing shrubs, grasses, legumes, and willows; use of jetties; and maintenance of buffer strips. Also describes combinations of structural and vegetative practices.

Lowdermilk, W. C. 1930. Influence of forest litter on runoff, percolation, and erosion. J. Forestry 28: 474-491. H

Luey, J. E. and I. R. Adelman. 1980. Downstream natural areas as refuges for fish in drainage-development watersheds. Trans. Am. Fish. Soc. 109: 332-335. D,O

Compared downstream fish fauna of three streams with varying degrees of upstream drainage development (including channel alterations). Found that downstream impacts of drainage development are less severe than impacts within modified areas. However, diversity and biomass of fish were highest in the least developed stream. Suggests that natural areas serve as reservoirs for stream biotas and should be preserved as refuges for fish species inhabiting those streams.

Lynch, J. A., E. S. Corbett, and R. Hoopes. 1977. Implications of forest management practices on the aquatic environment. Fisheries 2: 16-22. O

Good general review of the effects of forestry on streams.

Mackin, J. H. 1948. Concept of the graded river. Bull. Geol. Soc. Amer. 59: 463-512. I

Discusses relationships between water-sediment discharge and stream channel equilibrium

Marzolf. G. R. 1978. The potential effects of clearing and snagging on stream ecosystems. U.S. Fish and Wildl. Serv., Washington, D. C. FWS/OBS-78/14. H,N,O

Discusses the hydrological and biological effects of clearing and snagging, particularly in regard to functional aspects of stream ecosystems.

Matthews, W. J. 1980. Critical current speeds and microhabitat use by *Percina roanoke* and *Etheostoma flabellare* (Percidae). ASB Bulletin 27: 49. N

Matthews, W. J. and L. G. Hill. 1980. Habitat partitioning in the fish community of a southwestern river. Southwestern Nat. 25: 51-66. N

Examines microhabitats of four dominant fish species during an annual wet-dry cycle in a central Oklahoma river. Patterns of habitat usage by these fish reflected dispersal and segregation during relatively mild environmental conditions and convergence to similar microhabitats when conditions were rigorous.

Matthews, W. J. and J. D. Maness. 1979. Critical thermal maxima, oxygen tolerances and success of cyprinid fishes in a southwestern river. Am. Midl. Nat. 102: 374-377. N

Relates population dynamics of four minnow species during drought conditions to their temperature and dissolved oxygen tolerances in laboratory tests.

McConnell, C. A., D. R. Parsons, G. L. Montgomery, and W. L. Gainer. 1980. Stream renovation alternatives: the Wolf River story. J. Soil and Water Cons. 35: 17-20. E

Provides guidelines for minimizing biological impacts during clearing and snagging operations.

Meehan, W. R., F. J. Swanson, and J. R. Sedell. 1977. Influences of riparian vegetation on aquatic ecosystems with particular reference to salmonid fishes and their food supply. Pages 137-145 in Importance, Preservation and Management of Riparian Habitat: A Symposium. USDA, Forest Service, GTR-RM-43. N

Mendelson, J. 1975. Feeding relationships among species of *Notropis* (Pisces: Cyprinidae) in a Wisconsin stream. Ecological Monogr. 45: 199-230. J,L,N

Describes spatial distributions and food habits of four species of minnows. Suggests that adaptations that allow these fishes to live in particular regions of a pool and to feed on whatever prey is available in that microhabitat are important in permitting their coexistence.

Menge, B. A., and J. P. Sutherland. 1976. Species diversity gradients: Synthesis of the roles of predation, competition and temporal heterogeneity. American Naturalist 110: 351-359. N

Menzel, B. W. and H. L. Fierstine. 1976. A study of the effects of stream channelization and bank stabilization on warmwater sport fish in Iowa: Subproject No. 5: Effects of long-reach stream channelization on distribution and abundance of fishes. U. S. Fish and Wildl. Serv., FWS/OBS-76-15. B,C,N,O

Sampled fish from channelized and unchannelized prairie and woodland streams. Among the various habitat features studied, gradient was found to be most useful for explaining the distribution and abundance of fishes. The primary effect of channelization was a reduction in community diversity and stability. Channelized areas appear to act as travel corridors between favorable reaches of habitat and are of lower value as breeding and nursery areas for many species. Indicated that downstream high gradient reaches provide a high quality sport fishing resource, serve as refugia for fishes that are intolerant of prairie stream conditions, and may also contribute to recruitment of prairie stream stocks.

Merritt, R. W. and D. L. Lawson. 1978. Leaf litter processing in floodplain and stream communities. Pages 93-105 in Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. USDA, Forest Service. Washington, D. C., GTR-WO-12. J

Mills, ". B., W. C. Starrett, and F. C. Bellrose. 1966. Man's effect on the fish and wildlife of the Illinois River. Illinois Nat. Hist. Surv. Biol. Notes No. 57. 22 pp. C

Minckley, W. L. 1963. The ecology of a spring stream, Doe Run, Meade County, Kentucky. Wildl Monogr. 11. 124 pp. L

Morris, L. A., A. V. Mollitor, K. J. Johnson, and A. L. Leaf. 1978. Forest management of floodplain sites in the northeastern United States. Pages 236-242 in Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. Symp. Proc., USDA, Forest Service, Washington, D. C., GTR-WO-12. D

Forest management is suggested as a suitable use for regulated floodplain lands (i.e., those lands used for flood control).

Muncy, R. J., G. J. Atchison, R. V. Bulkley, B. W. Menzel, L. G. Perry, and R. C. Summerfelt. 1979. Effects of suspended solids and sediments on reproduction and early life of warmwater fish: a review. U. S. Environmental Protection Agency, Corvallis, Oregon. EPA-600/3-79-042. 101 pp. O

Musgrave, G. W. and G. R. Free. 1936. Some factors which modify the rate and total amount of infiltration of field soils. J. Amer. Soc. Agronomy 28: 727-739. H

Discusses importance of vegetation to infiltration capacity of soils.

Newbold, J. D., D. C. Erman, and K. B. Roby. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. Can. J. Fish. Aquat. Sci. 37: 1076-1085. D

Suggests that buffer strips of 30 m or wider were effective in preventing major impacts of logging on benthic macroinvertebrates.

Nickelson, T. E. and R. E. Hafele. 1978. Streamflow requirements of salmonids. Oregon Dept. Fish and Wildl., Ann. Proj. Rep., Fish Res. Proj: AFS-62. N,O

Relates various habitat parameters, including pool volume, cover, velocity, and wetted area, to standing crop of steelhead and cutthroat trout and juvenile coho salmon.

Nielsen, D. N., R. N. Vose, C. R. Fremling, and D. R. McConville. 1978. Phase I study of the Weaver-Belvidere area of the Upper Mississippi River. Report to the GREAT-I by Winona State College and St. Mary's College. 225 pp. F

North, R. M., A. S. Johnson, H. O. Hillestad, P. A. R. Maxwell, and R. C. Parker. 1974. Survey of economic-ecologic impacts of small watershed develpment. Tech. Comp. Rep. ERC 0974. Inst. Nat. Res. Univ. of Georgia, Athens, Ga. O

Compared fish and macrobenthos in channelized and unchannelized streams in the Georgia Piedmont. Fish production in the channelized stream, which had been modified eight years earlier, was similar to that of the unchannelized stream. However, species composition was markedly different in the two streams. Suggests that the nature of the primary channel modifications whereby only sections of the stream were modified, and the lack of maintenance of the channel since the project was completed, have enhanced biological recovery.

Nunnally, W. R. 1978. Stream renovation: An alternative to channelization. Envir. Manag. 2: 403-411. E,J,K

Describes the major hydraulic changes brought about by stream and land-use modifications. Presents guidelines for improving the flood flow efficiency of small stream channels.

Nunnally, N. R. and E. Keller. 1979. Use of fluvial processes to minimize adverse effects of stream channelization. Univ. North Carolina Water Res. Research Inst. 79-144. D,E,I,J,K

Proposes a methodology for increasing discharge while minimizing erosion and other environmental degradation associated with channelization. Includes a good discussion of fluvial processes and their relationship to channel form and stability. These relationships form the basis of stream restoration- a process for designing, constructing, maintaining, or restoring channels to equilibrium conditions.

Odum, E. P. 1969. The strategy of ecosystem development. Science 164: 262-270. D

Paloumpis, A. A. 1958. Responses of some minnows to flood and drought conditions in an intermittent stream. Iowa State J. Sci. 32: 547-561. N

Suggests that survival of fish populations in streams is possible during droughts and floods because favorable conditions persist in limited habitats. These "stream havens" include small tributary streams (e.g., during floods) and isolated pools during droughts.

Paragamian, V. L. 1980. Population dynamics of smallmouth bass in the Maquoketa River and other Iowa streams. Fed. Aid to Fish Restoration Compl. Rep. No. 602. Stream Fisheries Invest. Proj. No. F-89-R, 66 pp. N

Found habitat selectivity among a number of small river and stream fishes. Smallmouth bass density and standing stock were significantly correlated with the proportion of coarse gravel and cobble substrate in small rivers. However, in small tributary streams smallmouth bass were restricted more by water depth and availability of windfalls for cover than bottom type.

Paragamian, V.L. 1981. Some habitat characteristics that affect abundance and winter survival of smallmouth bass in the Maquoketa River, Iowa. Pages 45-53 in L. A. Krumholz (ed.) Warmwater Streams Symposium. Southern Division American Fisheries Society. N

Parsons, D. A. 1963. Vegetative control of streambank erosion. Pages 130-136 in Proc. Federal Interagency Sedimentation Conf., USDA-ARS, Washington, D. C., Misc. Publ. 970. E,J

Gives a number of valuable suggestions regarding the use of vegetation for streambank protection.

Patric, J. H. 1975. Timber harvest as an agent of forest stream channel modification. In R. V. Corning, R. F. Raleigh, G. D. Schuder, Sr., and A. Wood (eds.) Stream Modification Symp., Harrisonburg, Va. K

Patterson, D. W. 1976. Evaluation of habitats resulting from streambank protection projects in Siskiyou and Mendocino counties, California. Paper presented at 7th Ann. Joint Conf. Western Sect. Wildl. Soc. and Calif.-Nevada Chapt. Am. Fish. Soc., Fresno, California. E,F

Pflieger, W. L. 1975. The Fishes of Missouri. Mo. Dept. of Cons. 343 pp. M,N

Platts, W. S. 1979. Relationships among stream order, fish populations, and aquatic geomorphology in an Idaho river drainage. Fisheries 4: 5-9. L,N

Reice, S. R. 1974. Environmental patchiness and the breakdown of leaf litter in a woodland stream. Ecology 55: 1271-1282. N,O

Risser, J. 1981. A renewed threat of soil erosion: it's worse than the Dust Bowl. Smithsonian 11: 120-131. B

Sachet, J. A. 1977. A channel stability inventory for two streams on the eastern slopes of the coast range, Oregon. M.S. Thesis. Dept. of Geography, Oregon State Univ. Corvallis Ore. H

Sanderson, G. C. (ed.) 1980. Projected effects of increased diversion of Lake Michigan water on the environment of the Illinois River valley. Report for the Chicago District, U. S. Army Corps of Engineers. Prepared by Illinois Natural History Survey, Havana and Urbana, Illinois. C

Schlosser, I. J. 1981a. Fish community structure and function along two habitat gradients in a headwater stream. Manuscript submitted to Ecology. C,L,N

Discusses structure of warmwater stream fish communities along two gradients: upstream to downstream and riffle to pool. Combines knowledge of habitat structure and volume, with food availability in space and time to discuss recruitment dynamics and growth patterns in stream fishes along the two gradients. Both the stream continuum hypotheses and nonequilibrium conditions created by seasonal and between year variation in rainfall regimes are important determinants of fish community attributes.

Schlosser, I. J. 1981b. Fish community organization in natural and modified headwater streams. Manuscript submitted to Can. J. Fish. and Aquat. Sci. C,L,O

Two streams (one natural and one highly modified) are compared. Physical habitat attributes, food resource availability, and fish assemblages were studied. Concludes that stream modification in headwater areas have major impacts on fish communities throughout a watershed. The shift in modified streams toward shallow temporally variable physical environments create fish communities regulated by nonequilibruim processes.

Schramm, H. L., Jr. and W. M. Lewis. 1974. Study of importance of backwater chutes to a riverine fishery. Fish. Res. Lab., Southern Ill. Univ. Carbondale. U. S. Army Corps Eng. Contract DACW 39-73-0015. 145 pp. M

Describes the importance of backwater areas to zooplankton, phytoplankton, benthic invertebrates, macrophytes and fish. Concludes that over half of the riverine fish species found in the study area would be adversely affected by the loss of backwater habitat.

Schumm, S. A. 1971. Fluvial geomorphology: the historical perspective. Chapts. 4 and 5 in H. W. Shen (ed.). River Mechanics. Water Resources Pub., Fort Collins, Colo. H,I,K

Discusses relationships between river channel structure and characteristics of drainage basins.

Sheldon, A. L. 1968. Species diversity and longitudinal succession in stream fishes. Ecology 49: 193-198. L,N

Found that depth was the most important factor accounting for variation in fish species richness and diversity along a longitudinal gradient. Pointed out that the presence of cover led to local increases in species diversity and that high water velocities seemed to reduce the effective depth because fish could not occupy the entire water column.

Shelford, V. E. 1911. Ecological succession. Stream fishes and the method of physiographic analysis. Biol. Bull. 21: 9-35. L,N

Concludes that fishes have definite habitat preferences in streams which have a graded series of conditions from mouth to source.

Shen, H.W., S.A. Schumm, J.D. Nelson, D.O. Doehring, M.M. Skinner, and G.L. Smith. 1981. Methods for assessment of stream-related hazards to highways and bridges. Federal Highway Administration , Washington, D.C. Rept. No. FHWA/RD-80/160. 241 pp.

Shirazi, M. A. and W. K. Seim. 1979. A stream systems evaluation - an emphasis on spawning habitat for salmonids. U. S. Environmental Protection Agency, Corvallis, Oregon. EPA-600/3-79-109. N

Simons, D. B. and E. V. Richardson. 1966. Resistance to flow in alluvial channels. U. S. Geol. Surv. Prof. Paper 422-J. 61 pp. I

Simons, D. B., P.F. Lagasse, Y.H. Chen, and S. A. Schumm. 1975. The River Environment: A reference document. Colorado State Univ., Fort Collins. I

Slobodkin, L. B. and H. L. Sanders. 1969. On the contribution of environmental predictability to species diversity. Pages 82-95 in Diversity and Stability in Ecological Systems. Brookhaven National Laboratory. Upton, New York. N

Smart, H. J. and J. H. Gee. 1979. Coexistence and resource partitioning in two species of darters (Percidae), Etheostoma nigrum and Percina maculata. Can. J. Zoology 57: 2061-2071. N

Describes food and habitat segregation by different age groups, including seasonal distribution patterns.

Smith, P. W. 1971. Illinois streams: A classification based on their fishes and an analysis of factors responsible for disappearance of native species. Illinois Natural History Survey, Biological Notes 76. 14 pp. C

Smith, P. W. 1979. The Fishes of Illinois. Univ. of Ill. Press, Urbana, Ill. 313 pp. C,N

Sorensen, D. L., M. M. McCarthy, E. J. Middlebrooks, D. B. Porcella. 1977. Suspended and dissolved solids effects on freshwater biota: a review. Ecological Research Series, U. S. Environmental Protection Agency, Corvallis, Oregon. EPA-600/3-77-042. O

Sparks, R. E. 1977. Environmental inventory and assessment of navigation pools 24, 25, and 26, upper Mississippi and lower Illinois rivers: an electrofishing survey of the Illinois River. Special Rept. No. 5, Water Resources Center, Univ. of Illinois, Urbana, Illinois. C

Stall, J. B. and C. T. Yang. 1972. Hydraulic geometry and low stream flow regimen. Univ. of Illinois Water Res. Ctr., Res. Rept. No. 54. I

Describes a hierarchy of levels through which a stream system can adjust its potential energy expenditure. Suggests that the "law of least time rate of energy expenditure" governs fluvial processes.

Starrett, W. C. 1951. Some factors affecting the abundance of minnows in the Des Moines River, Iowa. Ecology 32: 13-27. N

Relates discharge characteristics to recruitment and population dynamics of minnows. Indicates that reproductive success is dependent upon the timing of high flows relative to the spawning periods of various species. Also suggests that the amount of space available during the low water stages and the extent to which this space is occupied by minnows and possibly other species may control to a considerable extent the success of reproduction each year. Thus, floods may have a beneficial effect by thinning populations and providing space for young fish.

Stegman, J. L. and W. L. Minckley. 1959. Occurrence of three species of fishes in interstices of gravel in an area of subsurface flow. Copeia 1959: 341. N

Found slender madtom, fantail darter and banded sculpin in the interstices of loosely constituted gravel.

Swales, S. and K. O'Hara. 1980. Instream habitat improvement devices and their use in freshwater fisheries management. J. Environ. Manage. 10: 167-179. F

Reviews stream habitat improvement devices.

Tarzwell, C. M. 1937. Experimental evidence on the value of trout stream improvement in Michigan. Trans. Amer. Fish. Society 66: 177-187. N

Thurston, R. V., R. C. Russo, C. M. Fetterolf, Jr., T. A. Edsall, and Y. M. Baber, Jr. (eds.). 1979. A review of the EPA Red Book: Quality Criteria for Water. Water Quality Section, American Fisheries Soc. Bethesda, Md. 313 pp. A

Toth, L. A. 1978. Resource partitioning between two species of darters, *Etheostoma caeruleum* and *Etheostoma flabellare*. M. S. Thesis. Northern Illinois Univ., Dekalb, Ill. 133 pp. N

Discusses food and habitat segregation by rainbow and fantail darters in a small stream.

Toth, L. A., D. R. Dudley, J. R. Karr, and O. T. Gorman. 1982. Natural and man-induced variability in a silverjaw minnow (*Ericymba buccata*) population. American Midland Naturalist. In Press. O

Relates population dynamics to stream habitat conditions and modifications.

Toth, L. A., J. R. Karr, O. T. Gorman, and D. R. Dudley. 1981. Temporal instability in the fishes of a disturbed agricultural watershed. Pages 165-230 in Environmental Impact of Land Use on Water Quality. Final Report on the Black Creek Project. Phase II. U. S. Environmental Protection Agency, Chicago, Illinois. EPA-905/9-81-003. L,O

Short- and long-term effects of stream alterations and other watershed modifications resulting in extreme variation in flow regimes and choking algal blooms are cited as causes of population variation and instability in a fish community.

Tramer, E. J. and P. M. Rogers. 1973. Diversity and longitudinal zonation in fish populations of two streams entering a metropolitan area. Am. Midl. Nat. 90: 366-374. L

Found that variation in species richness and diversity did not follow a consistent pattern along a longitudinal gradient. Rather, diversity was dependent on local substrate and water quality conditions and in some cases on conditions immediately upstream or downstream. Concludes that water quality parameters upset the normal pattern of longitudinal zonation and cancel diversity-enhancing effects of increased physical heterogeneity.

Trautman, M. B. 1957. The Fishes of Ohio. Ohio State University Press, Columbus, Ohio. M,N

Trautman, M. B. and D. K. Gartman. 1974. Re-evaluation of the effects of man-made modifications on Gordon Creek between 1887 and 1973 and especially as regards to its fish fauna. Ohio J. Sci. 74: 162-173. O

Triska, F. J. and K. Cromack, Jr. 1979. The role of wood debris in forests and streams. In R. H. Waring (ed.) Forests: Fresh Perspectives from Ecosystem Analysis. Proc. 40th Ann. Biol. Colloq., Oregon St. Univ., Corvallis, Oregon. J,N

Depicts wood debris as playing a major role in directing water flow and sediment storage. Discusses the value of wood debris as habitat for stream communities and as a long-term nutrient source. Recommends that maintenance of wood debris should be included in management programs.

U. S. Dept. of Agriculture. 1940. Influences of vegetation and watershed treatment on runoff, silting, and stream flow. USDA, Washington, D. C., Misc. Publ. No. 397, 80 pp. H

Describes relationships between vegetative cover and watershed hydrology.

U. S. Department of Agriculture. 1980. Appraisal 1980: Soil and Water Resources Conservation Act. Review Draft. Part I, Part II, Summary, Program Report and Environmental Impact Statement. USDA, Washington, D. C. 4 vols. G

U. S. Dept. of Agriculture. 1981. A Time to Choose: Summary Report on the Structure of Agriculture. USDA, Washington, D.C. B,G

USDA Soil Conservation Service. 1971. Planning and design of open channels. Pages 1-17 (Ch. 7) in Channel Design, Installation, and Maintenance. Technical Release No. 25, USDA, SCS. Washington, D. C. E

USDA Soil Conservation Service. 1975. Engineering Field Manual for Conservation Practices. E

USDA Soil Conservation Service. 1977,1979(amended). National Handbook of Conservation Practices. E

Vanderford, M. J. (ed.). 1980. Fish and wildlife work group I, final report to the Great River Environmental Action Team I. Vol. 5a. 336 pp. B,D,K,M,O

Documents modifications of the upper Mississippi River since the early 1800's and describes aquatic habitat resulting from lock and dam construction and dredging. Presents guidelines and recommendations for preserving fishery resources.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Can. J. Fish Aquat. Sci. 37: 130-137. C,N

Suggests that the physical structure of rivers coupled with the hydrologic cycle result in consistent patterns of community structure and function and organic matter dynamics and processing along the longitudinal gradient. Hypothesizes that the biological organization in rivers conforms structurally and functionally to kinetic energy dissipation patterns of the physical system.

Vanoni, V. A. 1975. Sedimentation Engineering. Am. Soc. Civil Eng., New York, N. Y. I

Wallace, D. C. 1972. The ecology of the silverjaw minnow, *Ericymba buccata* (Cope). Am. Midl. Nat. 87: 172-190. N

Describes detailed habitat preferences of silverjaw and bluntnose minnow. The two species exhibit subtle differences in current and depth distribution.

Wharton, C. H. and M. M.Brinson. 1978. Characteristics of Southeastern River Systems. Pages 32-40 in Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. Symp. Proceedings. USDA, Forest Service GTR-WO-12. J,N

Focuses on the importance of floodplains to biotic food chains and water quality characteristics of rivers. Discusses the value of floodplain sloughs, backwaters, and pools, tributary streams, and headwater swamps in meeting specific habitat requirements of fish and invertebrates.

White, R. J. and O. M. Brynildson. 1967. Guidelines for management of trout stream habitat in Wisconsin. Wisc. Dept. Nat. Res., Tech. Bull. No. 39, 64 pp. E,F,N

Discusses methods and devices for improving in- and nearstream habitat.

Whiteside, B. G. and R. M. McNatt. 1972. Fish species diversity in relation to stream order and physicochemical conditions in the Plum Creek drainage basin. Am. Midl. Nat. 88: 90-101. L,N

Suggests that the general increase in species with increasing stream order was due to addition of new stable habitats. The lower order streams were subject to drying up during frequently occurring periods of low rainfall and are repopulated by species from higher orders.

Winn, H. E. 1958. Comparative reproductive behavior and ecology of fourteen species of darters (Pisces: Percidae). Ecol. Monogr. 28: 155-191. N

Describes seasonal, interspecific, and intraspecific habitat differences in darters.

Witten, A. L. and R. V. Bulkley. 1975. A study of the effects of stream channelization and bank stabilization on warmwater sport fish in Iowa: Subproject No. 2. A study of the impact of selected bank stabilization structures on game fish and associated organisms. U. S. Fish and Wildl. Serv., Washington, D. C. FWS/OBS-76-12. E

Found that bank stabilization structures such as retards and jetties had measurable impacts on stream habitat and invertebrates but little apparent affect on local game-fish populations. In fact, deep scour holes produced by these structures were beneficial to some species.

Wolman, M. G. and J. P. Miller. 1960. Magnitude and frequency of forces in geomorphic processes. J. Geology 68: 54-74. I

Wyrick, G. 1968. U. S. Geological Survey statement for inter-agency stream disturbance symposium. Pages 44-45 in D. W. Robinson and A. D. Gerwig (eds.) Proc. Inter-agency Stream Disturbance Symposium. Charleston, W. Va. K

Yang, C. T. 1971a. Potential energy and stream morphology. Water Resour. Res. 7: 311-322. I

Discusses stream channel equilibrium relative to potential energy expenditure.

Yang, C.T. 1971b. Formation of riffles and pools. Water Resour. Res. 7: 1567-1574. I

Gives a detailed description of riffle and pool formation.

Yang, C. T. 1971c. On river meanders. J. Hydrology 13: 231-253. I

Examines the hydrology of a natural stream and the processes by which it adjusts to maintain equilibruim. Lists water discharge, valley slope, sediment concentration, and geological characteristics as independent variables and channel slope and channel geometry as the dependent variables involved in channel adjustment.

Zimmer, D. W. and R. W. Bachmann. 1976. A study of the effects of stream channelization and bank stabilization on warmwater sport fish in Iowa: Subproject No. 4. The effects of long-reach channelization on habitat and invertebrate drift in some Iowa streams. U. S. Fish and Wildlife Service. FWS/OBS-76-14. I,K

Found that channelization led to a reduction in variability of stream depth and current velocity as well as a probable reduction in the quantity of water stored in the channel during low flows. Moreover, sinuosity and variability in depth and current velocity did not approach natural levels in channelized streams even after 20 to 60 years of recovery.

Zon, R. 1927. Forests and water in the light of scientific investigation. Final Report Nat. Waterways Comm. 1912, 62nd Congress, 2nd session. Senatorial Doc. 469, 106 pp. H

Discusses the relation of forests to watershed hydrology.

APPENDIX I

LIST OF COMMON AND SCIENTIFIC NAMES OF ALL FISHES MENTIONED IN TEXT

PETROMYZONTIDAE
Silver Lamprey - *Ichthyomyzon unicuspis*

ACIPENSERIDAE
Lake Sturgeon - *Acipenser fulvescens*
Shovelnose Sturgeon - *Scaphirhynchus platorynchus*

POLYDONTIDAE
Paddlefish - *Polydon spathula*

LEPISOSTEIDAE
Longnose Gar - *Lepisosteus osseus*
Shortnose Gar - *L. platostomus*

AMIIDAE
Bowfin - *Amia calva*

ANGUILLIDAE
American Eel - *Anguilla rostrata*

CLUPIDAE
Skipjack Herring - *Alosa chrysochloris*
Alabama Shad - *A. alabamae*
Gizzard Shad - *Dorosoma cepedianum*

HIODONIDAE
Goldeye - *Hiodon alosoides*

SALMONIDAE
Cisco - *Coregonus artedii*
Coho Salmon - *Oncorhynchus kisutch*
Cutthroat Trout - *Salmo clarki*
Rainbow (Steelhead) Trout - *S. gairdneri*
Brook Trout - *Salvelinus fontinalis*

UMBRIDAE
Central Mudminnow - *Umbra limi*

ESOCIDAE
Grass Pickerel - *Esox americanus*
Northern Pike - *E. lucius*

Appendix I (continued - page 2)

CYPRINIDAE

Goldfish - *Crassius auratus*
Carp - *Cyprinus carpio*
Speckled Chub - *Hybopsis aestivalis*
Bigeye Chub - *H. amblops*
Horneyhead Chub - *Nocomis biguttatus*
Pallid Shiner - *Notropis amnis*
Emerald Shiner - *N. atherinoides*
Blacknose Shiner - *N. heterolepis*
Bigeye Shiner - *N. boops*
Common Shiner - *N. cornutus*
Pugnose Minnow - *N. emiliae*
Spotfin Shiner - *N. spilopterus*
Sand Shiner - *N. stramineus*
Redfin Shiner - *N. umbratilis*
Topeka Shiner - *N. topeka*
Blacktail Shiner - *N. venustus*
River Shiner - *N. blennius*
Ghost Shiner - *N. buchanani*
Striped Shiner - *N. chrysocephalus*
Suckermouth Minnow - *Phenacobius mirabilis*
Bluntnose Minnow - *Pimephales notatus*
Bullhead Minnow - *P. vigilax*
Blacknose Dace - *Rhinichthys atratulus*
Creek Chub - *Semotilus atromaculatus*
Common Stoneroller - *Campostoma anomalum*

CATOSTOMIDAE

White Sucker - *Catostomus commersoni*
Blue Sucker - *Cycleptus elongatus*
Smallmouth Buffalo - *Ictiobus bubalus*
Bigmouth Buffalo - *I. cyprinellus*
Black Buffalo - *I. niger*
River Carpsucker - *Carpiodes carpio*
Quillback - *C. cyprinus*
Highfin Carpsucker - *C. velifer*
Northern Hogsucker - *Hypentelium nigricans*
Blacktail Redhorse - *Moxostoma poecilurum*
Golden Redhorse - *M. erythrurum*
Shorthead Redhorse - *M. macrolepidotum*
Silver Redhorse - *M. anisurum*

Appendix I (continued - page 3)

ICTALURIDAE

Channel Catfish - *Ictalurus punctatus*
Blue Catfish - *I. furcatus*
Black Bullhead - *I. melas*
Yellow Bullhead - *I. natalis*
Flathead Catfish - *Pylodictis olivaris*
Slender Madtom - *Noturus exilis*
Stonecat - *N. flavus*

APHREDODERIDAE

Pirate Perch - *Aphredoderus sayanus*

ATHERINIDAE

Brook Silverside - *Labidesthes sicculus*

PERCICHTHYIDAE

White Bass - *Morone chrysops*

CENTRARCHIDAE

Rock Bass - *Ambloplites rupestris*
Bluegill - *Lepomis macrochirus*
Green Sunfish - *L. cyanellus*
Longear Sunfish - *L. megalotis*
Warmouth Sunfish - *L. gulosus*
Spotted Sunfish - *L. punctatus*
Largemouth Bass - *Micropterus salmoides*
Smallmouth Bass - *M. dolomieui*
Black Crappie - *Pomoxis nigromaculatus*
White Crappie - *P. annularis*

PERCIDAE

Greenside Darter - *Etheostoma blennoides*
Rainbow Darter - *E. caeruleum*
Fantail Darter - *E. flabellare*
Orangebelly Darter - *E. radiosum*
Johnny Darter - *E. nigrum*
Orangethroat Darter - *E. spectabile*
Bluntnose Darter - *E. chlorosonum*
Slough Darter - *E. gracile*
Yellow Perch - *Perca flavescens*
Blackside Darter - *P. maculata*
Sauger - *Stizostedion canadense*
Walleye - *S. vitreum*
Pikeperch - *S. lucioperca*

SCIAENIDAE

Freshwater Drum - *Aplodinotus grunniens*

APPENDIX II. ABUNDANCE, POPULATION TRENDS, AND ECOLOGICAL CLASSIFICATIONS OF FISHES OF THE ILLINOIS RIVER BASIN. NOTE - KEY AT END OF TABLE FOR SUPERSCRIPTS.

	Current Relative Abundance[a]	Population Trend Since 1850[b]	Typical Stream Size[c]	Food Habits[d]
PETROMYZONTIDAE				
Chestnut Lamprey = *Ichthyomyzon castaneus*	UNC	S-I	MR-LR	P
Northern Brook Lamprey - *I. fossor*	R	S	HW-MR	Pl
Silver Lamprey - *I. unicuspis*	UNC	D	MR-LR	P
American Brook Lamprey - *Lampetra lamottei*	R	D	HW-MR	Pl
ACIPENSERIDAE				
Lake Sturgeon -*Acipenser fulvescens*	R	D	LR	Inv
Shovelnose Sturgeon - *Scaphirhynchus platorynchus*	R	D	LR	Inv
POLYDONTIDAE				
Paddle fish - *Polydon spathula*	R	D	LR-MR	Pl
LEPISOSTEIDAE				
Spotted Gar - *Lepisosteus oculatus*	R	D	MR	I/P
Longnose Gar - *L. osseus*	UNC	S	LR-MR	I/P
Shortnose Gar - *L. platostomus*	C	S	LR-MR	I/P
Alligator Gar - *L. spatula*	Ex.	Ex.	LR	P
AMIIDAE				
Bowfin - *Amia calva*	UNC	D	MR	I/P
ANGUILLIDAE				
American eel - *Anguilla rostrata*	UNC	D	LR	P
CLUPEIDAE				
Skipjack herring - *Alosa chrysochloris*	UNC	D	LR	I/P
Gizzard shad - *Dorosoma cepedianum*	A	I	LR-MR	Omn
HIODONTIDAE				
Goldeye - *Hiodon alosoides*	UNC	S	LR	I/P
Mooneye - *H. tergisus*	R	D	LR-MR	I

Appendix II (continued - page 2)

	Current Relative Abundance[a]	Population Trend Since 1850[b]	Typical Stream Size[c]	Food Habits[d]
SALMONIDAE				
Cisco - Coregonus artedii	Ex	Ex	Lake -LR	Pl
Rainbow Trout - Salmo gairdneri	Sporadic Introductions			I/P
OSMERIDAE				
Smelt - Osmerus mordax	R	Introduced	Lake-LR	I/P
UMBRIDAE				
Central Mudminnow - Umbra limi	UNC	S	HW	Omn
ESOCIDAE				
Grass Pickerel - Esox americanus	UNC	D	MR-HW	I/P
Northern Pike - E. lucius	UNC	D	MR	I/P
CYPRINIDAE				
Goldfish - Crassius auratus	C	(Intro.) I	MR	Omn
Southern Redbelly Dace - Phoxinus erythrogaster	UNC	D	HW	Herb
Carp - Cyprinus carpio	VC	(Intro.) D	MR-LR	Omn
Grass Carp - Ctenopharyngodon idella	R	(Intro.) S	LR-MR	Herb
Silverjaw Minnow - Ericymba buccata	UNC	S	MR-HW	Inv
Silver Chub - Hybopsis storeriana	UNC	D	LR-MR	Inv
Speckled Chub - H. aestivalis	UNC	S	LR	Inv
Gravel Chub - H. x-punctata	Ex	Ex	HW	?
Horneyhead Chub - Nocomis biguttatus	C	D	HW	Inv
Golden Shiner - Notemigonus crysoleucas	C	D	LR-MR	Omn
Emerald Shiner - Notropis atherinoides	VC	D	LR-MR	Inv
Blacknose Shiner - N. heterolepis	R	D	HW	Omn
Bigeye Shiner - N. boops	R	D	MR-HW	Inv
Common Shiner - N. cornutus	UNC	D	HW	Inv
Pugnose Minnow - N. emiliae	R	D	MR	Inv
Spottail Shiner - N. hudsonius	VC	S	LR-MR	Inv
Rosyface Shiner - N. rubellus	UNC	D	MR	Inv
Spotfin Shiner - N. spilopterus	UNC	D	MR-HW	Inv
Sand Shiner - N. stramineus	A	S	MR-HW	Inv
Redfin Shiner - N. umbratilis	C	S	HW	Inv
Pugnose Shiner - N. anogenus	Ex	Ex	Lake-MR	?
River Shiner - N. blennius	UNC	D	MR-LR	Inv
Ghost Shiner - N. buchanani	UNC	D	LR	?

Appendix II. (continued - page 3)

	Current Relative Abundance[a]	Population Trend Since 1850[b]	Typical Strea Size[c]	Food Habits[d]
Ironcolor Shiner - *N. chalybaeus*	UNC	S	HW	Inv
Striped Shiner - *N. chrysocephalus*	C	D	HW-MR	Inv
Bigmouth Shiner - *N. dorsalis*	VC	I	HW-MR	Omn
Red Shiner - *N. lutrensis*	VC	I	HW-MR	Inv
Silverband Shiner - *N. shumardi*	UNC	S	LR	?
Weed Shiner - *N. texanus*	R	D	HW-LR	?
Mimic Shiner - *N. volucellus*	R	D	MR	Omn
Steelcolor Shiner - *N. whipplei*	R	D	HW-MR	Inv
Ozark Minnow - N. nubilis	Ex	Ex	HW	Herb
Silvery Minnow - *Hybognathus nuchalis*	VC	D	MR	Herb
Suckermouth Minnow - *Phenacobius mirabilis*	C	D	MR-HW	Inv
Bluntnose Minnow - *Pimephales notatus*	A	S	HW-MR	Omn
Fathead Minnow - *P. promelas*	VC	I	HW	Omn
Bullhead Minnow - *P. vigilax*	C	D	MR-LR	
Blacknose Dace - *Rhinichthys atratulus*	UNC	D	HW	Omn
Creek Chub - *Semotilus atromaculatus*	A	I	HW	Inv
Common Stoneroller - *Campostoma anomalum*	C	S	MR-HW	Herb
Largescale Stoneroller - *C. oligolepis*	UNC	D	HW	Herb
CATOSTOMIDAE				
White Sucker - *Catostomus commersoni*	VC	S	MR-HW	Inv
Creek CHubsucker - *Erimyzon oblongus*	R	D	HW	Inv
Lake Chubsucker - *E. sucetta*	R	D	HW	Inv
Spotted Sucker - *Minytrema melanops*	R	D	HW-MR	Inv
Blue Sucker - *Cycleptus elongatus*	R	D	LR-MR	?
Smallmouth Buffalo - *Ictiobus bubalus*	C	S	LR-MR	Inv
Bigmouth Buffalo - *I. cyprinellus*	C	D	LR-MR	Plank
Black Buffalo - *I. niger*	R	S	LR-MR	Inv
River Carpsucker - *Carpiodes carpio*	C	S	LR-MR	Omn
Quillback - *C. cyprinus*	VC	I	MR	Omn
Highfin Carpsucker - *C. velifer*	R	D	LR-MR	Omn
Northern Hogsucker - *Hypentelium nigricans*	UNC	D	MR-HW	Inv
River Redhorse - *Moxostoma carinatum*	R	D	HW-MR	Inv
Golden Redhorse - *M. erythrurum*	C	D	MR	Inv
Shorthead Redhorse - *M. macrolepidotum*	UNC	S	MR	Inv
Greater Redhorse - *M. valenciennesi*	Ex	Ex	MR	?
Silver Redhorse - *M. anisurum*	R	D	MR	Inv
Black Redhorse - *M. duquesnei*	R	S	MR	Inv

Appendix II (continued - page 4)

	Current Relative Abundance[a]	Population Trend Since 1850[b]	Typical Stream 1850[c]	Food Habits[d]
ICTALURIDAE				
Channel Catfish - Ictalurus punctatus	C	D	MR-LR	Omn
White Catfish - I. catus	R	N	LR-Lake	I/P
Blue Catfish - I. furcatus	R	S	LR-MR	I/p
Black Bullhead - I. melas	C	D	MR-HW	Inv
Yellow Bullhead - I. natalis	C	I	MR-HW	Inv
Brown Bullhead - I. nebulosus	R	D	MR-HW	Inv
Flathead Cathead - Pylodictis olivaris	UNC	S	LR-MR	I/P
Slender Madtom - Noturus exilis	R	D	HW	Inv
Stonecat - N. flavus	UNC	D	MR-HW	Inv
Tadpole Madtom - N. gyrinus	UNC	D	HW	Inv
Freckled Madtom - N. nocturnus	R	D	MR-LR	Inv
CYPRINODONTIDAE				
Banded Killifish - Fundulus diaphanus	Ex	Ex	HW	Inv
Blackstripe Topminnow - F. notatus	C	S	HW	Inv
Starhead Topminnow - F. dispar	UNC	D	LR-Lake	Inv
POECILIIDAE				
Mosquitofish - Gambusia affinis	UNC	(Intro.) S	HW	Inv
PERCOPSIDAE				
Trout-Perch - Percopsis omiscomaycus	R	D	MR	Inv
APHREDODERIDAE				
Pirate Perch - Aphredoderus sayanus	R	D	HW-MR	Inv
GADIDAE				
Burbot - Lota lota	R	D	LR	I/P
ATHERINIDAE				
Brook Silverside - Labidesthes sicculus	UNC	D	MR-LR	Inv
GASTEROSTEIDAE				
Brook Stickleback - Culaea inconstans	UNC	D	HW	Inv
Ninespine Stikleback - Pungitius pungitius	R	D	Lake-LR	Inv

Appendix II (continued - page 5)

	Current Relative Abundance[a]	Population Trend Since 1850[b]	Typical Stream 1850[c]	Food Habits[d]
COTTIDAE				
Mottled Sculpin - Cottus bairdi	R	S	HW	Inv
Banded Sculpin - C. carolinae	R	S	HW	I/P
PERCICHTHYIDAE				
White Bass - Morone chrysops	C	S	LR	I/P
Yellow Bass - M. mississippiensis	R	D	LR-Lake	I/P
CENTRARCHIDAE				
Rock Bass - Ambloplites rupestris	C	D	MR	I/P
Bluegill - Lepomis macrochirus	C	S	MR	I/P
Green Sunfish - L. cyanellus	VC	S	HW	I/P
Orangespotted Sunfish - L. humilis	C	D	HW-MR	I/P
Longear Sunfish - L. megalotis	R	D	MR-HW	I/P
Pumpkinseed Sunfish - L. gibbosus	UNC	D	MR-HW	I/P
Redear Sunfish - L. microlophus	R	Sporadic Intro.	MR-HW	Inv
Warmouth Sunfish - L. gulosus	UNC	D	MR-HW	I/P
Spotted Sunfish - L. punctatus	R	D	MR	?
Bantam Sunfish - L. symmetricus	Ex	Ex	MR	Inv
Largemouth Bass - Micropterus salmoides	C	(Intro.) S-D	LR-MR	I/P
Smallmouth Bass - M. dolomieui	C	D	MR	I/P
Black Crappie - Pomoxis nigromaculatus	C	D	LR,MR	I/P
White Crappie - P. annularis	C	D	LR,MR	I/P
PERCIDAE				
Western Sand Darter - Ammocrypta clara	Ex	Ex	MR-LR	Inv
Mud Darter - Etheostomaasprigene	UNC	D	LR-MR	Inv
Rainbow Darter - E. caeruleum	C	D	HW-MR	Inv
Iowa Darter - E. exile	Ex	Ex	MR-HW	Inv
Fantail Darter - E. flabellare	UNC	D	HW-MR	Inv
Least Darter - E. microperca	U	D	HW	Inv
Johnny Darter - E. nigrum	VC	D	MR-HW	Inv
Orangethroat Darter - E. spectabile	VC	S	HW	Inv
Bluntnose Darter - E. chlorosonum	UNC	D	HW-LR	Inv
Slough Darter - E. gracile	R	S	HW-LR	Inv
Banded Darter - E. zonale	R	D	HW-LR	Inv
Yellow Perch - Perca flavescens	UNC	D	LR,MR	I/P
Logperch Darter - Percina caprodes	UNC	D	MR-HW	Inv

Appendix II (continued - page 6)

	Current Relative Abundance[a]	Population Trend Since 1850[b]	Typical Stream 1850[c]	Food Habits[d]
Blackside Darter - *P. maculata*	UNC	D	HW	Inv
Slenderhead Darter - *P. phoxocephala*	UNC	D	MR-LR	Inv
River Darter - *P. shumardi*	R	D	LR	Inv
Sauger - *Stizostedion canadense*	R	D	MR-LR	I/P
Walleye - *S. vitreum*	R	D	MR	I/P
SCIAENIDAE				
Freshwater Drum - *Aplodinotus grunniens*	C	D	MR-LR	I/P

KEY

[a] Current relative abundances; from Allison and Hothem 1975

A - Abundant. A species so numerous as to be usually one of the dominant species.

VC - Very common. A species which is readily catchable, usually in large numbers.

C - Common. A species, which, considering its catchability under various conditions and times, is found usually in moderate to large numbers.

UNC - Uncommon. A species occuring rather regularly in collections, but usually in small numbers.

R - Rare. A species recorded only once or very infrequently, and invariably in small numbers.

Ex - Extirpated. A species that is no longer found in the watershed.

[b] Population trend

S - Stable. No major change in abundance.

I - Increase. Significant increase in abundance.

D - Decrease. Significant decrease in abundance.

(Intro.) - Introduced. Non-native species now present through release or invasion and native species whose presence is due primarily to stocking and escape from ponds.

Ex - Lost. Species whose numbers have been so drastically reduced they are considered extirpated or extremely rare.

[c] Major habitat; stream size category

HW - headwaters

MR - Intermediate-sized rivers

LR - Large rivers

[d] Food habit category based on information found in Carlander 1969, 1977, Smith 1978, Karr & Dudley 1978.

Inv - Invertivore

I/P - Invertivore/Piscivore

Pl - Planktivore

Omn - Omnivore

Herb - Herbivore

P - Piscivore

Source of information
- general form, habitat and food habits data, Karr and Dudley 1978
- population status, food habits, and habitat data, Smith 1979
- faunistic surveys of Ill. Natural History Survey, unpub.
- life history and habitat data, Pflieger 1975
- life history and habitat data, Hubbs and Lagler 1958